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TREC TECHNICAL REPORT 61-12

AIRCRAFT MOORING EQUIPMENT

FINAL REPORT

Task 9M89-02-015-08

June 1961

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**DEPARTMENT OF THE ARMY
TRANSPORTATION CORPS**

FINAL REPORT

**Task 9M89-02-015-08
(Formerly Project 9-89-02-000, Task 114AV)**

AIRCRAFT MOORING EQUIPMENT

June 1961

Prepared by

Robert M. Bernardin, Project Engineer

**U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA**

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SUMMARY

This report covers the initial work leading to the development of aircraft ground mooring equipment that can be transported by an Army aircraft without impairing its normal functions. The aircraft mooring system program was initiated in response to a directive from the Office, Chief of Transportation (OCOFT). Standard mooring devices available from military and commercial sources were tested and evaluated. Results of tests indicated that all of the tested items were inadequate for Army aviation use.

It was determined that a research and development program would be required to fulfill the overall requirements of a mooring system suitable for Army aircraft. A staff study was prepared to establish parameters and design objectives for a complete aircraft mooring system. A contract was awarded in June 1959 for the research and development of a system that would be more satisfactory than the Standard D-1 Anchor Kit developed by the Air Force and currently being used by the Department of the Army.

Proposals for optimum mooring patterns and design data indicating the location of mooring points on future aircraft designs were submitted by the contractor. However, no suitable tie-down anchors and attaching components were developed; therefore, the mooring system is not complete.

Studies and tests conducted under this project, test data obtained from the U. S. Army Test Board, and recent reports of damage to aircraft located at Camp Breckenridge, Kentucky, show the need for continuous efforts in order to improve the present mooring system.

CONCLUSIONS

It is concluded that:

1. The objective of the Aircraft Mooring Equipment Project has not been attained.
2. A prerequisite for the attainment of an optimum mooring system is the development of an acceptable ground anchor.
3. Additional field evaluation tests based on data obtained during the performance of the mooring system program are necessary to determine the adequacy of the proposed optimum mooring system.
4. Additional information is required in order to develop suitable mooring equipment for the extreme conditions encountered in arctic areas.

BACKGROUND

OCOFT has directed that continuous research be conducted on a flyaway aircraft mooring kit until one is developed that is acceptable for standardization. Project 9-89-02-000, Subtask 114AV, subsequently redesignated Task 9-89-015-08 (Appendix I), was approved for the purpose of designing and developing ground mooring equipment to protect Army aircraft from being damaged by high winds when the aircraft is parked on soil or frozen surfaces.

The immediate objective of the task was to develop mooring equipment that was capable of being transported by an individual aircraft without impairing the performance of the aircraft's normal functions. The ultimate objective was to classify the developed item(s) as standard Army equipment.

Initial efforts were concentrated on the continuation of an investigation of mooring equipment available from both commercial and military sources. Included in the acquired data were test reports covering ground-holding capabilities of the Standard D-1 Anchor Kit, developed by the Quartermaster Corps; and a variety of commercial ground anchors. An evaluation of the test reports showed contradictory results. A program was therefore initiated to perform comparative tests on the same anchors to obtain valid test data to determine which anchors were most suitable for aircraft mooring. These tests are covered in Part I of Test Procedures and Results. The tests showed that the Quartermaster Universal Ground Anchor was the most suitable for use in aircraft mooring, although none of the anchors adequately fulfilled the military and technical characteristics. (These characteristics are listed in Appendixes II and III respectively.)

In order to attain the immediate objective of the task, a staff study was prepared during April 1959 to establish investigative parameters for development of an aircraft mooring system suitable for Army aviation use. The staff study indicated that in order to establish design criteria for adequate mooring equipment, it would be necessary to establish aircraft mooring parameters based on requirements generated by the wide variety of Army aircraft.

Mooring requirements vary in proportion to the size and type of aircraft in the system. The U-1A, for example, is a large aircraft by Army standards.

The loads generated by wind reaction on this aircraft are of necessity much greater than those generated on the L-19. Since it is not feasible to provide a separate mooring anchor for each aircraft according to its requirements, a balance must be achieved that will provide adequate capabilities without adding excess weight. Thus, a greater number of anchors to withstand wind forces may be required for large aircraft than would be required for small aircraft. It was also recognized that certain advantages could be gained by both the optimum location of mooring points on aircraft and the formulation of an optimum mooring pattern for each individual aircraft. A contract was therefore awarded to study and investigate these various facets and to formulate an optimum mooring system for Army aircraft.

The contractor's engineering report, covering a mooring system proposed as the optimum for Army aviation use, is included in this report as Part 3 of Test Procedures and Results. However, the mooring system cannot be considered as being complete until an acceptable anchor has been developed. To aid in the development of a suitable anchor, the contractor included data in the engineering report that pertained to ground anchor requirements for Army aircraft, based on wind velocities of 75 knots. (Technical manuals recommend that aircraft be placed in a hangar or evacuated if the wind velocity is higher than 75 knots. Damage has been caused by winds with a velocity of considerably less than 75 knots. In June 1960, several different types of aircraft at Camp Breckenridge, Kentucky, were severely damaged by high winds. Tie-down ropes were broken, and tie-down rings embedded in concrete were pulled out.)

As the result of a directive from Headquarters, U. S. Continental Army Command, the U. S. Army Arctic Test Board conducted tests during March and April of 1960 at Fort Greely, Alaska, to determine whether the Universal Ground Anchor was suitable to replace the Standard Arrow for tie-down equipment for use under arctic conditions. This report of test is included as Part 2 of Test Procedures and Results.

TEST PROCEDURES AND RESULTS

PART 1. CURRENTLY AVAILABLE MOORING DEVICES

DETERMINATION. Anchor Holding Power in Various Soils

Procedure

In August 1957, tests were conducted at Red Beach and the Proving Grounds at Fort Eustis, Virginia, and at Camp Wallace, Virginia, to determine the

holding power, ease of installation, and recoverability of six mooring devices. Each item was tested in both wet and dry soil, sand, loam, and clay. The devices were driven into the ground as near one another as was believed possible without affecting the holding power of any one item. Each anchor was slowly drawn from the ground by a hydraulic crane, and measurements were made with a chatillon dynamometer (recording spring scale), as shown in Figure 1. Static load-carrying ability was determined in the sand tests because some of the items could be withdrawn from sand by hand if the devices were oscillated slightly. No effort was made to determine static load-carrying ability in other types of ground.



Figure 1. Hydraulic Hoist Used in Pull-Testing Mooring Devices.

Results

The Universal Ground Anchor (Figure 2), developed as a tent pin by the Quartermaster Corps in accordance with specification MIL-A-3962, was the easiest to install and the most reliable under all conditions. It has a design strength of 1,500 pounds, which limits its holding power under some conditions. It is recoverable only by digging.

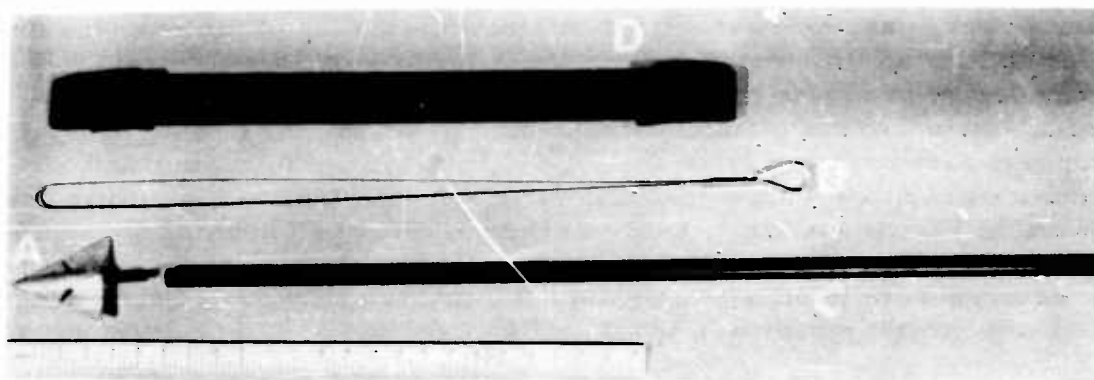


Figure 2. Universal Ground Anchor With Components.

In Figure 2, "A" shows the anchor spearpoint; "B", the 30-inch guy wire; "C", the 36-inch driving rod; and "D", the wooden holding handle.

The Standard Arrow (Figures 3 and 4), developed by the Air Force as a light-aircraft mooring device in accordance with specifications MIL-K-6102 and MIL-A-20383, held well under most conditions but was unreliable in wet clay and wet sand. The installation would have been satisfactory if the driving rod had not had a tendency to bend. Although the shaft and ring were recoverable, the shaft bent excessively when any load was applied. The threads of the rod and ring were plated; in most cases, the plating came off during assembly and thus left little thread. In some cases, the shaft and ring failed during the test and could not be re-used.

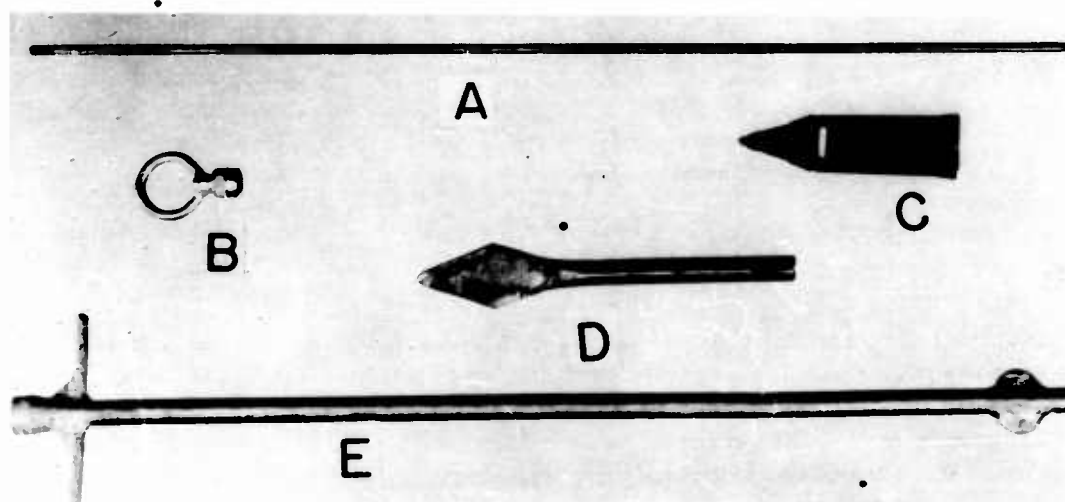


Figure 3. Standard Arrow With Components.

Figure 3 shows the following components from the Standard D-1 Anchor Kit: "A" shows the shaft; "B", the shaft ring; "C", the arrow; "D", the starting tool; "E", the driving rod.

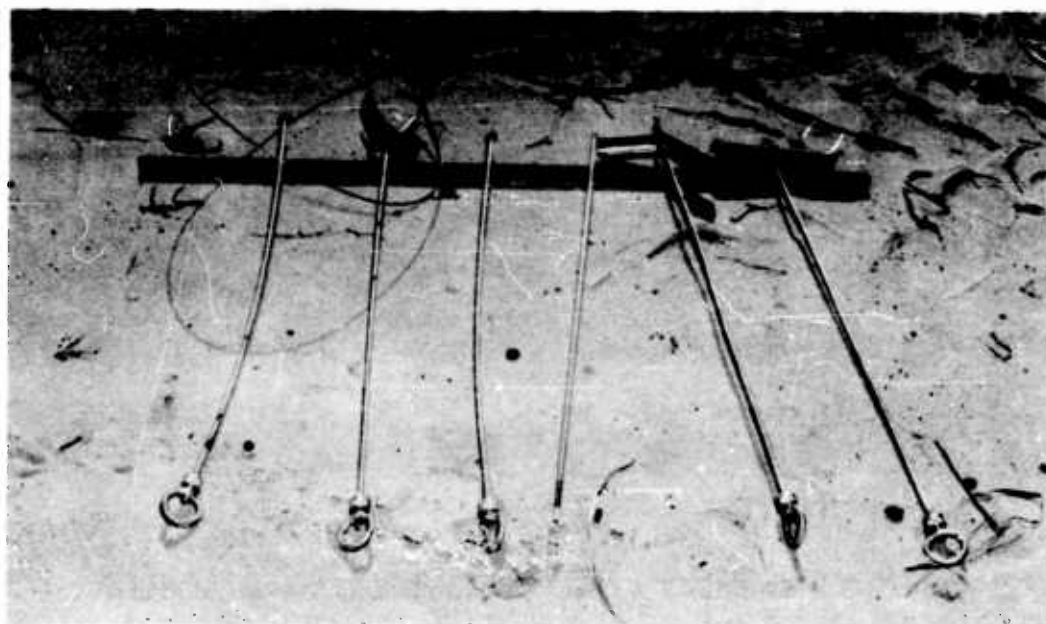


Figure 4. Condition of Standard Arrow After Extraction From Sand.

The first and third arrows in Figure 4 show that the hex nut has been pulled from the head; the fourth rod shows where the threads have been stripped.

As shown in Figure 5, stiffeners were welded to the head of the Standard Arrow in the design of the Modified Standard Arrow. The modified anchor failed to surpass the Standard Arrow in any phase of the tests and was inferior in many ways.

The Seaplane Auger is shown in Figure 6. Since this device was designed for use on sand beaches, it was installed in sand with little difficulty. It demonstrated a holding power almost equal to that of the Universal Ground Anchor. In other soils, its installation varied from difficult to impossible. It is recoverable in most cases.

The Barbed Wire Entanglement Securing Pin (Figure 7), developed in accordance with specification MIL-P-20635, proved to be so difficult to install in soils other than sand that tests were suspended.

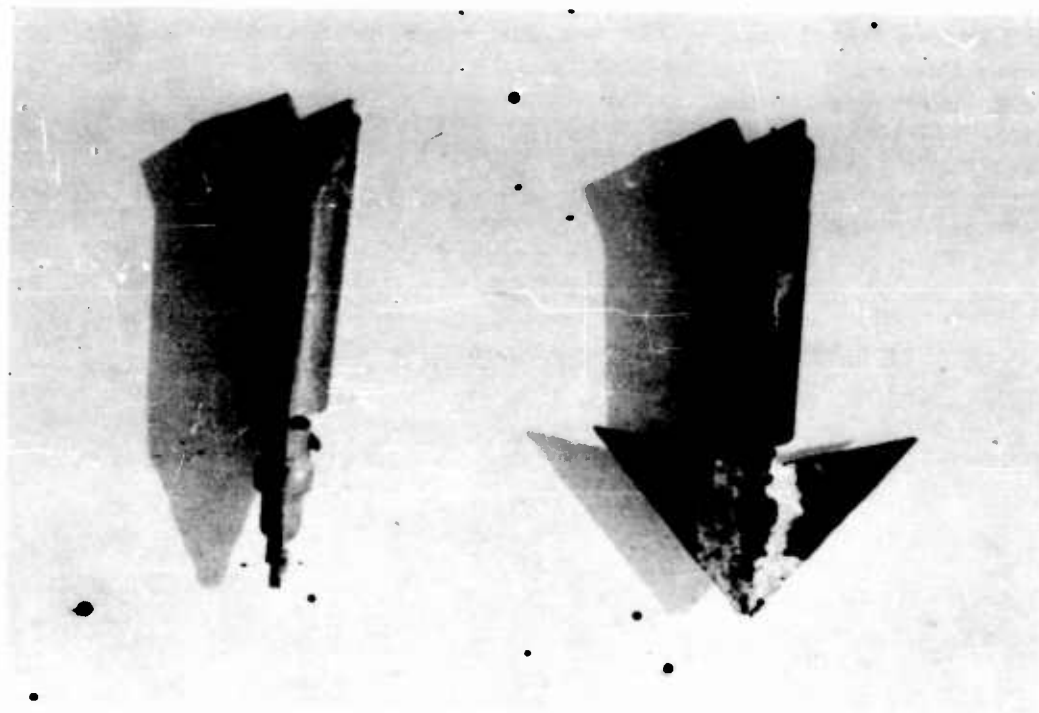


Figure 5. Standard Arrow and Modified Standard Arrow.

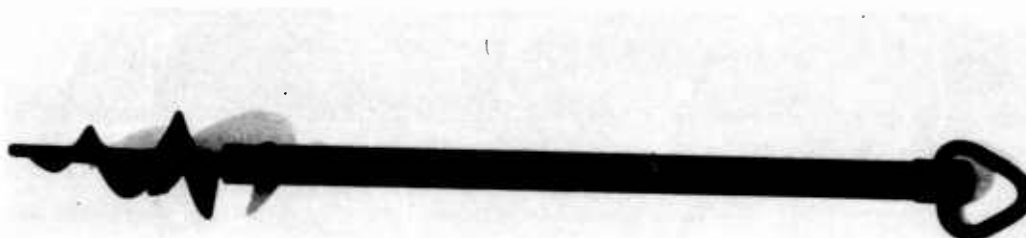


Figure 6. Seaplane Auger.



Figure 7. Barbed Wire Entanglement Securing Pin.

The Spade Pin (Figure 8), designed by the Aviation Directorate of U. S. Army Transportation Research Command as an experimental model, proved to have poor holding qualities in sand and light soil and had to be dug from hard soil in order to be recovered. Even after the Spade Pin was reinforced, it bent when it was extracted from dry clay (Figure 9).



Figure 8. Experimental Spade Pin, Unassembled.

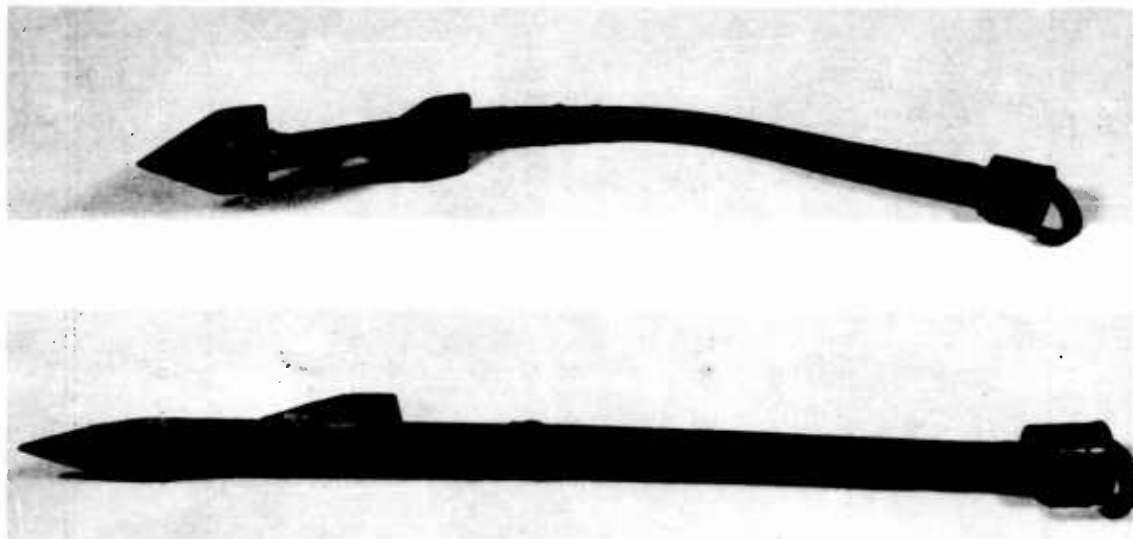


Figure 9. Condition of Spade Pin After Being Pulled From Dry Clay.

SUMMARY OF RESULTS

Table 1 shows comparative results of the anchors tested in various types of ground; and Table 2, the retention capabilities of the anchors.

TABLE I
SUMMARY COMPARISON OF ITEMS TESTED

Type	Unit	Holding Power	Ease of Installing	Recoverability
Anchor	Weight			
Universal Ground Anchor	9 oz. without driving rod	Excellent when driven at 90° and pulled at 45° to 60°	Excellent	Not recoverable
Standard Arrow	11.5 oz. without driving rod	Good when driven at 90° and pulled at 45° to 60°	Good	Good except for head
Modified Standard Arrow	13 oz. without driving rod	Fair; did not exceed Standard Arrow	Good	Good except for head
Experimental Spade Pin	6 lb. 5 oz.; could be lightened	Fair	Good	Good
Seaplane Auger	5 lb. 13 oz.	Good	Fair	Good
Barbed Wire Picket Pin	4 lb. 6 oz.	Good in sand only	Poor	Good

TABLE 2
RETENTION CAPABILITIES OF TESTED ANCHORS IN VARIOUS TYPES SOIL

Type Anchor	Type Ground	Ground Condition	Pounds of Pull						Remarks	Diagram of Retraction Tests
			Angles of Insertion/Extraction							
			90°/45°	90°/60°	60°/45°	60°/60°	45°/45°	45°/60°		
Univ. Ground Anchor	Lt. Soil	Wet	400	1,700	1,700	800	1,600	400	a Device was sunk at 90° and pulled at 90°. Wire broke, knocking register hand back. Probably failed above 1,500 lb. Wire broke in two other cases in wet sand. b Steady pull of 175 lb. vs. 75 lb. for Standard Arrow.	
		Dry	1,500	1,500	1,600	1,600	1,600	1,800		
	Clay	Wet	885	1,075	1,700	800	1,600	1,175		
		Dry	1,700	1,600	1,700	1,800	1,500	1,700		
	Loam	Wet	450	300	700	400	700	200		
		Dry	1,375	1,390	450	900	1,000	860		
Standard Arrow	Lt. Soil	Wet	1,525 ^a	1,975 ^a	690	1,550	1,510	1,510	c Hooked on root. d Prongs did not open. e Fitting ailed. f Another device was driven. Removed device by oscillating hand pull of 20 lb. These devices could not be re-used safely in all cases.	
		Dry	1,435	1,080	625	675	735	350 ^b		
	Clay	Wet	800	800	675	575	175 ^c	130		
		Dry	475	475	960	575	350	325		
Scapline Auger	Lt. Soil	Wet	2,600 ^g	1,400	2,300	1,600	1,500 ^h	1,500 ^h	g Nonrecoverable. h No further test required. i One auger broke at its shank. Failure apparently caused by fast chill in a pearlitic malleable casting. j Ball of clay stuck to screw. k No further test required. l Unable to insert.	
		Dry	2,800	1,775	2,300	1,400	2,100	1,775		
	Clay	Wet	1,600	1,600	1,700	900	600	600		
		Dry	UNABLE TO INSERT IN DRY CLAY							
	Loam	Wet	1,500 ^j	1,000	500	1,200	500	800		
		Dry	1,100 ^k	850	1,125	980	200	290		
Barbed Picket Pin	Lt. Soil	Wet	800	980	1,030	975 ⁱ	300	475	m No further test required. n Steady pull at 250 lb.; extracted pin, 90°/90°. Pine bent beyond use.	
		Dry	2,800 ^k							
	Clay	Wet	k							
		Dry	k							
	Loam	Wet	j							
		Dry	j							
Experimental Spade Pin	Lt. Soil	Wet	1,250	1,300	875	910	510	250	p SAME AS ABOVE	
		Dry	825	720	325	525	180	475		
	Clay	Wet								
		Dry								
	Loam	Wet								
		Dry								
Experimental Spade Pin	Lt. Soil	Wet	200						p SAME AS ABOVE	
		Dry	2,000							
	Clay	Wet								
		Dry								
Experimental Spade Pin	Loam	Wet							p SAME AS ABOVE	
		Dry								
	Sand	Wet	625 ^m	525	n	n	150	125		
		Dry	725	635	825	330	100	250		

PART 2. SERVICE TEST OF UNIVERSAL GROUND ANCHOR IN ARCTIC REGIONS

(Extracted from letter ATBE-AV (P-ATB 4-140), U. S. Army Arctic Test Board, 28 April 1960, subject: Report of Project Nr ATB 4-140, Service Test of 4-Inch Aluminum Ground Anchor Kit)

PURPOSE

The purpose of the test was to determine if the 4-inch aluminum Universal Ground Anchor Kit, packaged for aviation use, is suitable for replacing standard Army aircraft tie-down equipment for use under arctic winter conditions.

DESCRIPTION OF MATERIEL

The T53-9 4-inch QMC Universal Ground Anchor is a cast aluminum spearpoint-shaped device with a cast-in anchor pin (Figure 2). Two slots in the anchor are provided to accept an anchor wire. The anchor and anchor wire are driven straight into the ground by a steel driving rod until only the end of the anchor wire with the thimble remains above the ground. A wooden safety handle is provided to hold the steel driving rod while the anchor is being emplaced. The ground anchor kit as packaged for general field use contains 50 anchors, 50 anchor wires, 2 driving rods, 2 holding handles, and one set of instructions. No mooring rope is provided. The complete kit weighs approximately 52 pounds.

The Standard D-1 Anchor Kit was used as a control item in this project.

BACKGROUND

There presently exists in the supply system a Kit, Airplane Mooring, Type D-1, specification MIL-K-6102, which was designed specifically for tiedown of aircraft and is issued to all Army aviation units for mooring Army aircraft.

In January 1958, the United States Army Aviation Board was notified of the proposed service test of the aluminum Universal Ground Anchor developed by the Quartermaster Corps. As requested by USCONARC, the Aviation Board recommended possible uses for the ground anchor in Army Aviation.

Three anchor kits were received at this Board on 6 February 1960.

Information concerning tripartite standardization is not available.

SUMMARY OF TEST RESULTS

Test Nr 1--Physical Characteristics

The physical characteristics were found to be as stated in "Description of Materiel".

Test Nr 2--Operational Suitability

A total of 32 anchor spearpoints were used during the test. All of these spearpoints received a degree of damage (Figure 10) during an attempt to drive them into various types of hard frozen soil.

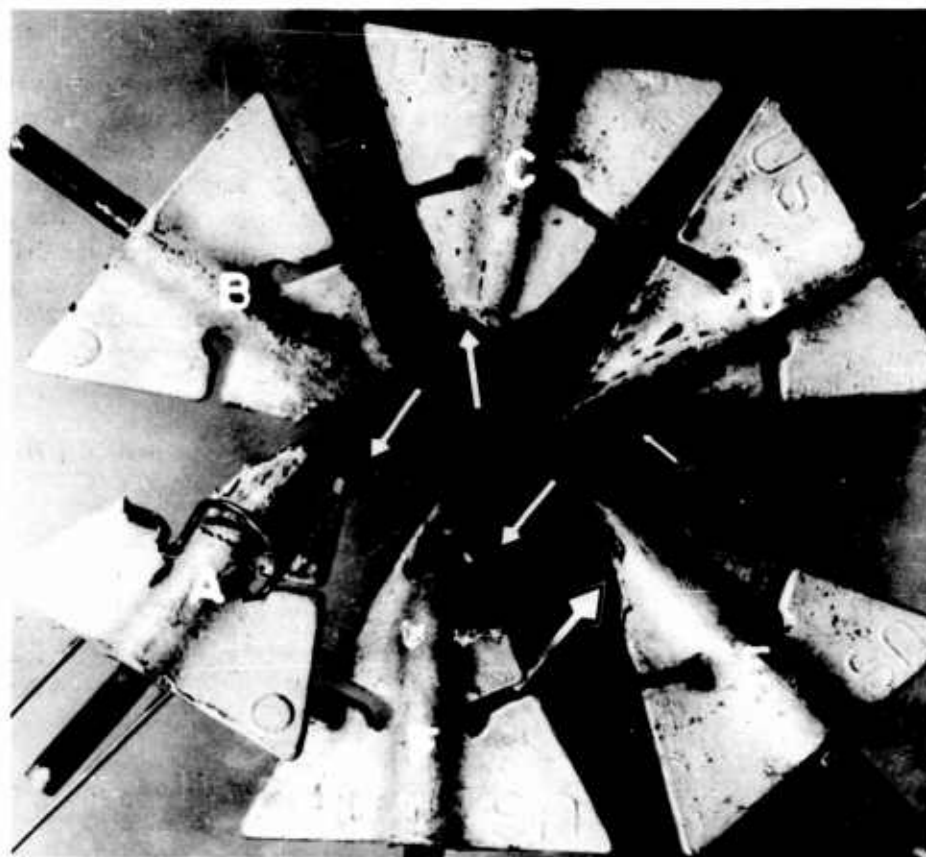


Figure 10. Damaged Arrows From the Universal Ground Anchor Kit. A--Damaged Spearpoint of Cold-Soaked Anchor Extracted From Frozen Ground. B Through F--Damaged Spearpoints of Anchors That Had Not Been Cold-Soaked.

During an attempt to drive the aluminum anchor into frozen sand, rocky soil, and frozen muskeg, a maximum depth of approximately 3-1/2 inches was attained. At this depth two men could very easily pull the anchor from the soil. High-wind aircraft tie-down tests were suspended for this reason.

During an attempt to drive the Standard Anchor (Figure 4) into frozen soils, the arrow first bent on the point and then separated from the shaft, losing all holding qualities (Figure 11).

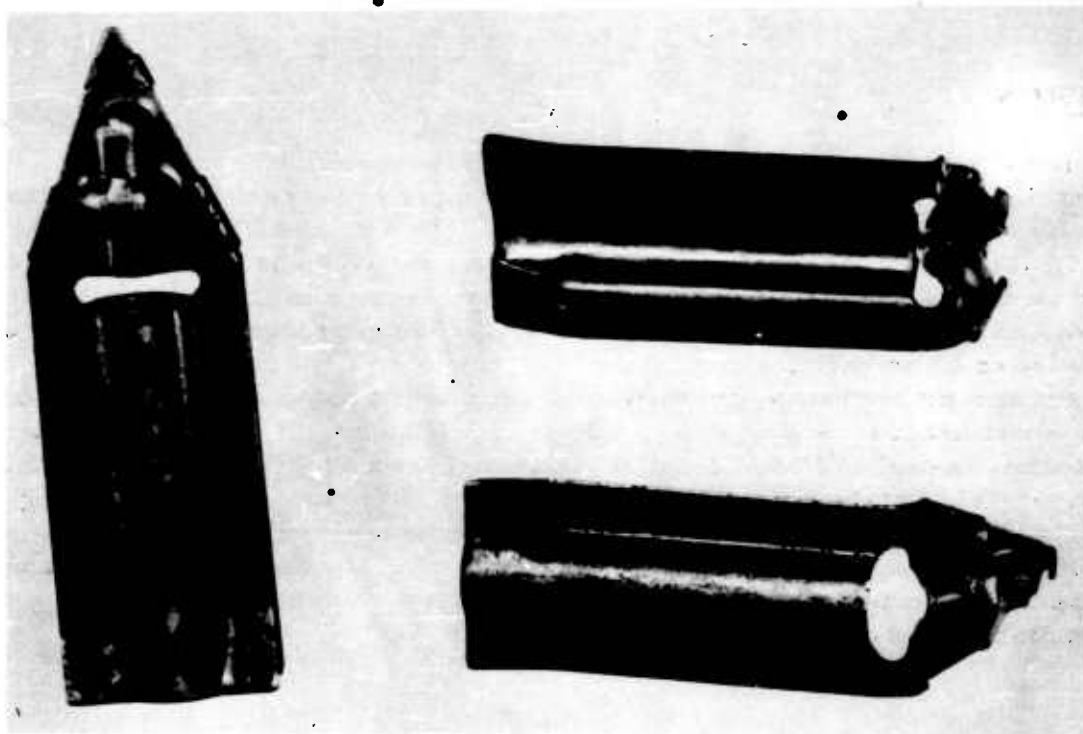


Figure 11. Standard Arrow Spearpoints--Before and After Installation in Frozen Soil.

During an attempt to drive the aluminum anchor into frozen soil, after being cold-soaked for a period of 24 hours at an ambient temperature of -20°F. to -44°F., the spearpoint cracked on the shank and one blade of the spearpoint broke off (Figure 10).

Personnel wearing arctic winter clothing, to include arctic mittens, encountered no difficulty in handling the anchor kits.

The wooden holding handle provided with the aluminum Universal Ground Anchor Kit was a distinct safety advantage, since the sledge-wielder was allowed to use maximum driving force without endangering the personnel holding the stake.

The instruction sheet included with the aluminum Ground Anchor Kit was adequate.

During the test, a 5-pound sledge and a single-blade axe were used to drive the anchors.

With the exception of the safety advantage provided by use of the wooden holding handle, there were no distinct advantages or disadvantages of the aluminum Ground Anchor Kit over the standard Army aircraft tie-down equipment (D-1) for use under arctic winter conditions.

DISCUSSION

During the entire test, it was impossible to drive stakes of either the Standard Anchor Kit (D-1) or the 4-inch aluminum Universal Ground Anchor Kit into hard frozen soils sufficiently to hold. During the 1959 test season, a service test of the AN/GRN-6 (Project Nr ATB 1557) was conducted, and similar trouble securing the guy wires with the issue aluminum stake was reported. A 6-inch steel piton was used as a field expedient during the test and was found to be satisfactory while the ground was frozen; however, during the spring break-up, these pitons were found to be unsatisfactory due to their short length. A guy stake, GP-112/G (Figure 12), which had been cold-weather tested at Fort Churchill, Canada, was supplied to correct this deficiency. This stake proved adequate for use in frozen soils and during spring break-up. The GP-112/G stake is quite heavy, weighing three pounds. It is the opinion of this board that a stake of similar material and weight is required to penetrate hard frozen soils to a depth sufficient to afford suitable holding qualities.

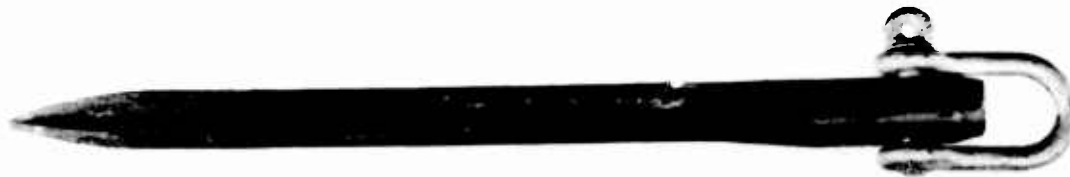


Figure 12. Guy Stake, GP-112/G.

CONCLUSIONS

It is concluded that:

1. The 4-inch aluminum Universal Ground Anchor Kit, packaged for aviation use, is unsuitable for replacing standard Army aircraft tie-down equipment for use under arctic winter conditions.
2. No further consideration should be given to the 4-inch aluminum Universal Ground Anchor Kit for aircraft tie-down use under arctic winter conditions.
3. The development should be continued to provide a suitable aircraft tie-down kit for use under arctic winter conditions.

RECOMMENDATIONS

It is recommended that:

1. The 4-inch aluminum Universal Ground Anchor Kit, packaged for aviation use, be considered unsuitable for replacing standard Army aircraft tie-down equipment for use under arctic winter conditions.
2. No further consideration be given to the 4-inch aluminum Universal Ground Anchor Kit for aircraft tie-down use under arctic winter conditions.
3. The development be continued to provide a suitable aircraft tie-down kit for use under arctic winter conditions.

PART 3. ENGINEERING REPORT--AIRCRAFT MOORING SYSTEM
(Prepared by Entwistle Manufacturing Company, 29 January 1960)

I. TECHNICAL OBJECTIVES:

The objectives of the contract are four:

1. To determine design considerations and technical specifications for the design of mooring points on future Army aircraft
2. To determine the optimum tie-down pattern for each standard Army aircraft
3. To determine an optimum, standard, single tie-down pattern for all current and projected Army aircraft
4. To develop preliminary design concepts for a fly-away mooring kit conforming to the Military and Technical Characteristics.

Objectives 1, 2 and 3 are the subject of this report while Objective 4 is the subject of a separate report entitled "Preliminary Design Report".

II. METHOD OF APPROACH:

To accomplish the above objectives, a general analysis of the static forces involved on an aircraft due to various winds is required. From this analysis, it will be possible to determine an optimum number of mooring points for an aircraft. The general analysis is then applied to each specific aircraft to determine the minimum number of mooring points, minimum number of mooring cables, and the optimum angular position of these mooring cables with respect to the aircraft. Accumulation of this data for each craft defines the optimum tie-down pattern for that craft.

Correlation and comparison of the various specific optimum tie-down patterns afford the basis for determination of the optimum, single, standard tie-down pattern. Upon completion of the above determinations it will be possible to establish design considerations for use in designing mooring points on future Army aircraft. Information necessary to the above analyses was collected from various sources, principally from the manufacturers of the specific aircrafts involved.

III. TERMINOLOGY:

For the sake of clarity and mutual understanding, definitions of various phrases and expressions are given as follows:

Mooring Point: A fitting or fixture on an aircraft provided for the purpose of tying the aircraft to the ground through tie-down cables.

Optimum Tie-Down Pattern: That pattern consisting of the minimum number of mooring points and minimum number of tie-down cables which will restrain movement of an aircraft under a maximum wind pressure without exceeding the maximum allowable structural stress in the aircraft.

Tie-Down Cable: Any line, rope, cable or chain with accessories that is used to tie the aircraft to the ground.

Optimum, Single, Standard Tie-Down Pattern: That pattern of ground mooring points at an aircraft parking apron which will allow any current or projected Army aircraft to be moored in a pattern closely resembling the Optimum Tie-Down Pattern for the particular aircraft.

Technical Specifications: Those design criteria which an aircraft designer must utilize when designing and locating mooring points on an aircraft.

Design Consideration: The reasons for, and evolution of, the Technical Specifications.

Army Aircraft: Those aircraft which are presently in use (referred to as "current") and those which, as presently believed, will be in use in the future (referred to as "projected"). The following list defines all the aircraft considered during this program study.

<u>MANUFACTURER</u>	<u>DESIGNATION</u>	<u>TYPE</u>	<u>CURRENT/ PROJECTED</u>
Beech Aircraft	L-23	Fixed Wing Tri-cycle Landing Gear	Current
Bell Helicopter	H-13	Helicopter with skids	Current
	HU1-A	Helicopter with skids	Current
Cessna Aircraft	L-19	Fixed Wing Conventional Landing Gear	Current
DeHavilland Aircraft	L-20	Fixed Wing Conventional Landing Gear	Current

<u>MANUFACTURER</u>	<u>DESIGNATION</u>	<u>TYPE</u>	<u>CURRENT/ PROJECTED</u>
DeHavilland Aircraft	U-1A	Fixed Wing Conventional Landing Gear	Current
	YAC-1	Fixed Wing Tricycle Landing Gear	Projected
Grumman Aircraft	AO1-A	Fixed Wing Tricycle Landing Gear	Projected
Heller Aircraft	H-23	Helicopter with skids	Current
Sikorsky Aircraft	H-19	Helicopter with 4-wheels	Current
	H-34	Helicopter with 3-wheels	Current
	H-37	Helicopter with 3-wheels	Current
Vertol Aircraft	H-21	Helicopter with 3-wheels	Current
	YHC-1	Helicopter with 3-wheels	Projected

IV. GENERAL ANALYSIS: -STATIC FORCES-

An analysis of the static forces involved on a moored aircraft is necessary to determine:

1. minimum required number of mooring points on any aircraft
2. formulae through which forces at these mooring points in the aircraft can be determined.
3. formulae through which the optimum angular location with respect to the aircraft can be determined for minimum forces in tie-down cables
4. formulae through which the maximum tie-down cable forces under given wind forces can be calculated.

Application of this analysis to specific aircrafts is treated in a subsequent section where the optimum number of mooring points, as well as, the optimum number and location of mooring cables will be determined for each aircraft. For clarity and easy reference all symbols used in this report are defined here and are also illustrated in the appropriate figures:

- C_d = Drag coefficient of aircraft in head wind
- C_l = Lift coefficient of aircraft in head wind
- C_s = Drag coefficient of aircraft in side wind
- C_l' = Lift coefficient of aircraft in side wind
- S = Planform area of airfoil
- S' = Characteristic area of aircraft upon which C_l' is based
- A = Characteristic area of aircraft upon which C_s is based
- a = Longitudinal distance between center lift (in head wind) and center of gravity in a direction toward main landing gear
- b = Longitudinal distance between center of gravity and auxiliary landing gear wheel axle
- c = Longitudinal distance aft between main landing gear wheel axles and center of gravity
- d_a = Diameter of auxiliary landing gear wheel
- e = Vertical distance down from center of gravity to the auxiliary mooring point
- f = Vertical distance between center of gravity and auxiliary landing gear axle
- g = Longitudinal distance between auxiliary landing gear wheel axle and the auxiliary mooring point in a direction away from the main landing gear
- h = Vertical distance down from center of gravity to main mooring point
- j = Longitudinal distance between center of gravity and main mooring point in a direction away from main landing gear
- l = Longitudinal distance toward auxiliary mooring point between main mooring point and center of pressure of the projected flat side area

in a plane parallel to the plane of symmetry

m = Longitudinal distance toward main mooring points between the center of pressure and the auxiliary mooring point

n = Lateral distance from plane of symmetry to the wing mooring point

p = Lateral distance from the plane of symmetry to the center of the landing gear wheel

q = Dynamic pressure of wind = $\frac{\rho v^2}{2}$

s = Vertical distance down from center of gravity to center of pressure

t = Longitudinal distance aft from center of gravity to center of lift on semi-span due to side wind

v = Lateral distance from the plane of symmetry to the center of lift of the semi-span due to a side wind

W = Weight of aircraft

x = Possible variation between assumed location and actual location of center of pressure in any direction

Θ = Angle between axis of roll due to side wind and plane of symmetry

$$(\tan \Theta = \frac{P}{b + c})$$

Headwind Forces:

The free-body diagram in Figure 1* is used to determine the magnitude and location of the forces F_1 and T_1 that are required to maintain equilibrium against a head wind.

Summing the horizontal forces, we have

$$F_1 = D_1 \quad \text{equation 1}$$

where D is the "drag" due to the head wind.

*A new series of figure numbers is introduced in this section. These numbers are not to be confused with the figure numbers used in Parts 1 and 2.

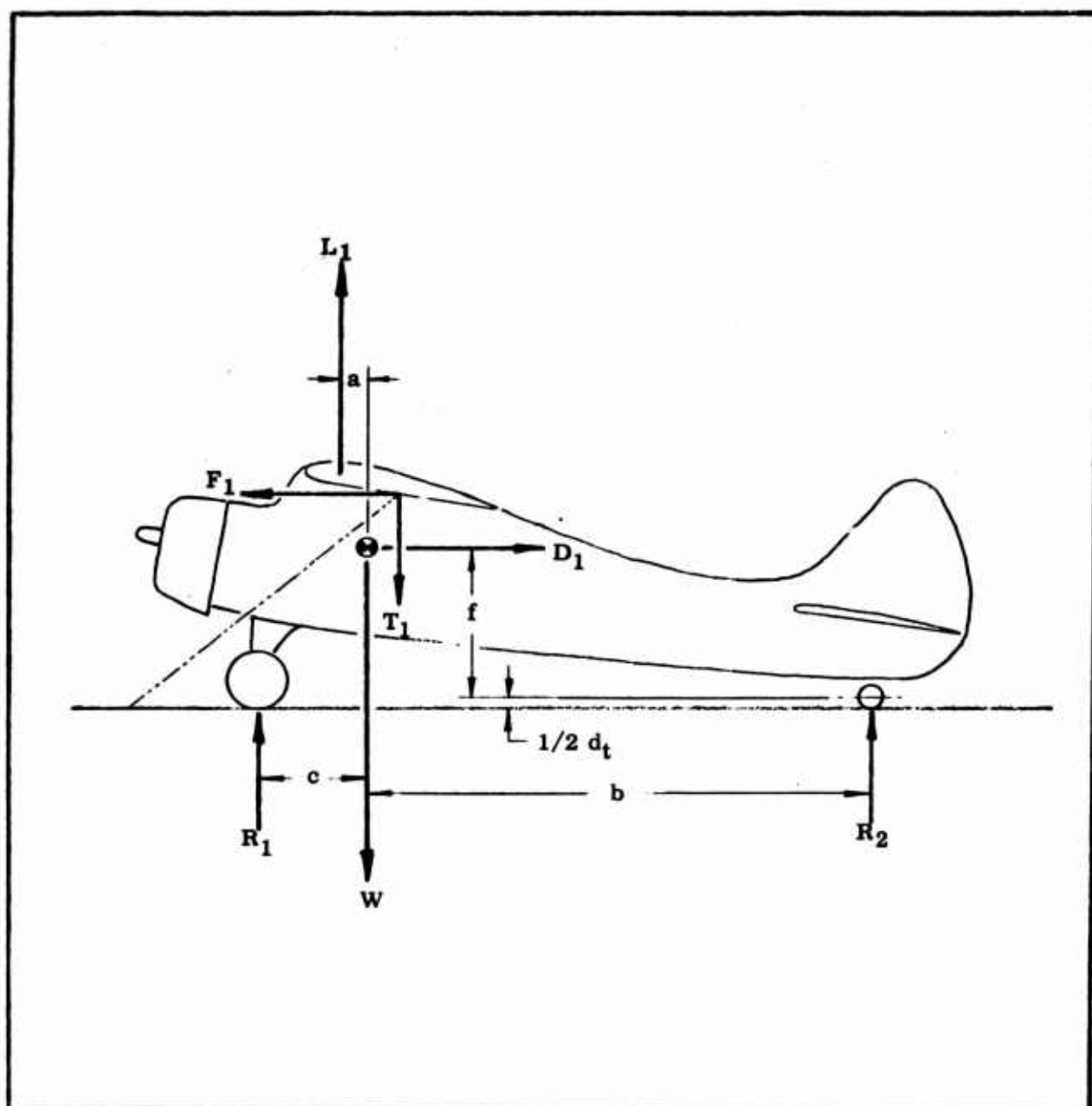


FIGURE 1

The "Drag" is defined as:

$$D_1 = C_d q S \quad \text{equation 2}$$

where C_d = experimentally determined drag coefficient
 q = dynamic wind pressure
 S = planform wing area

Prior to summing the vertical forces, special consideration must be given the force L , the Lift Force. The lift force is defined as:

$$L = C_l q S \quad \text{equation 3}$$

where C_l = experimentally determined lift coefficient
 q = dynamic wind pressure
 S = planform wing area

Unless the lift force is of sufficient magnitude, it will not affect the equilibrium of the aircraft. When it is sufficient to upset the equilibrium, there will be no reaction force at the forward landing gear, $R_1 = 0$, and then a vertical restraining force is required to hold the aircraft down. Under this condition, and referring to Figure 2 we can derive the following equations:

$$F_1 = D_1 = C_d q S \quad \text{equation 4}$$

$$T_1 = L - R_2 - W \quad \text{equation 5}$$

$$T_1 = \frac{L(a+b) - W(b) + F_1(h)}{(b-j)} \quad \text{equation 6}$$

Although it is reasonable to utilize one mooring point in the plane of symmetry for restraint against a head wind, it is better to utilize two mooring points spaced equal distances from the plane of symmetry. The reason for this will be seen in a subsequent section which analyzes the forces involved due to a side wind.

It should also be noted that the restraining forces T_1 and F_1 are assumed to be acting at a point below and aft of the center of gravity. The actual location of this mooring point, however, must be at a structurally sound position and its design must be such that it will not compromise the aerodynamic performance of the aircraft.

Equations 3, 4 and 6 above will determine the maximum necessary longitudinal and vertical components of a cable from P_1 which can hold an aircraft



in equilibrium against a head wind. Using two mooring points and one cable at each point, the forces at each mooring point would be one half of the forces F_1 and T_1

$$F_1' = 1/2 F_1 = 1/2 C_d q S \quad \text{equation 7}$$

$$T_1' = 1/2 T_1 = \frac{L(a+b) - W(b) + F_1(h)}{2(b-j)} \quad \text{equation 8}$$

Tail Wind Forces:

The Free-body diagram in Figure 3 is used to determine the magnitude and location of the forces F_2 and T_2 that are required to maintain equilibrium against a tail wind. Drag and Lift forces due to a tail wind are assumed to be equal in magnitude but opposite in direction to the drag and lift forces due to an equivalent head wind. Thus:

$$D_2 = C_d q S \quad \text{equation 9 (a)}$$

$$L_2 = C_l q S \quad \text{equation 10}$$

Assuming one tie-down in the plane of symmetry and located at the tail of the aircraft through which a horizontal force equal to F_2 and a vertical force equal to T_2 is exerted, and also assuming the worst case in which the wind force causes a large enough counterclockwise moment to cause the aircraft to tip nose down ($R_2 = 0$) we can derive that:

$$F_2 = D_2 = C_d q S \quad \text{equation 11}$$

$$T_2 = R_1 - W - L_2 \quad \text{equation 12}$$

$$T_2 = \frac{F_2(e) - L_2(c-a) - W(c)}{b+c+g} \quad \text{equation 13}$$

Side Wind Forces, Horizontal Plane:

The free-body diagram of Figure 4 is used to determine the forces involved to maintain equilibrium against a side wind. The resultant force on the side of an aircraft can be determined from the following formula:

$$D_3 = C_s q A \quad \text{equation 14}$$

where C_s is a coefficient dependent upon the geometry of the aircraft

q is dynamic wind pressure

A is a characteristic area of the aircraft upon which C_s is based

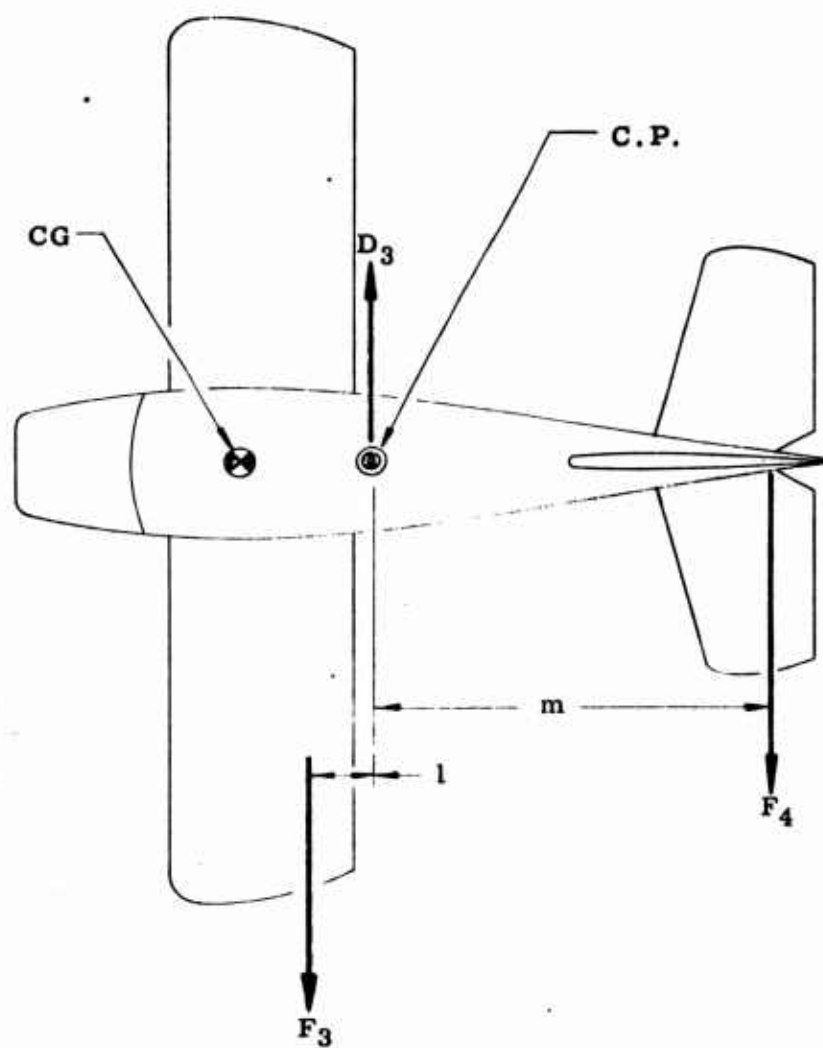


FIGURE 4

The quantities C_s and A are normally determined experimentally. Since no data is immediately available, approximations of these quantities will be used in subsequent calculations. The approximation, in each case, is stated where it is used.

The resultant force due to the side wind will act through the center of pressure. The center of pressure, is by definition, that point through which the resultant force due to a pressure distribution can be assumed to be acting.

Location of the center of pressure can only be accomplished experimentally. For large flat areas which are normal to the air flow, the assumption that the center of pressure is coincident with the centroid of the area is a valid assumption. This assumption will be used in locating the center of pressure of an aircraft.

Another assumption used in this analysis is that friction between the wheels of the aircraft and the ground is negligible. This condition will be closely approximated when the aircraft is moored on icy terrain and incorporates a measure of safety in the calculated cable loads.

From previous considerations of head winds and tail winds it is established that at least one mooring point is required to maintain equilibrium against each of these winds. It can quickly be deduced that two points are required to restrain an aircraft against each possible side wind. For this reason, it was assumed above that the mooring point required for restraint against a head wind will be separated into two points equidistant from the plane of symmetry. It is also preferred that a mooring point be located on the wing section during side winds to restrain against excessive deflection of the wing. If the wing were not moored while the fuselage is securely moored, excessive winds tending to lift the wing might cause excessive deflections and possible damage in the wing. Thus the mooring points already selected for use in head winds and in tail winds are utilized to restrain against side winds as is illustrated in Figure 4. From Figure 2 and 3, the distance between these two mooring points is $b - j + g$. From Figure 4:

$$b - j + g = l + m$$

where l and m are the horizontal distances from each mooring point to the centroid of the projected side area of the aircraft.

From Figure 4, then we can derive:

$$F_4 + F_3 = D_3 = C_s q A \quad \text{equation 15}$$

$$F_4 = C_s q A \left(\frac{l}{l + m} \right) \quad \text{equation 16}$$

$$F_3 = C_s q A \left(\frac{m}{l + m} \right) \quad \text{equation 17}$$

Equations 17 and 18 will determine the magnitude of the maximum horizontal lateral forces at the fore and aft mooring points. However, these forces are subject to an error depending upon the accuracy of the assumed position of the center of pressure.

From Figure 5, it can be seen that each reaction force, G_1 or G_2 , due to a load W at position "a" is a function of $\frac{a}{a+b}$. Were the dimension "a" to change by dimension "x" in either $\frac{a}{a+b}$ direction the reaction G_1 would change by $(\frac{x}{a})G_1$ while the reaction G_2 would change by $(\frac{x}{b})G_2$. The reaction toward which the shift occurs will increase while the opposite reaction decreases.

From this it follows that the reactions F_3 and F_4 can vary by a percentage equal to the possible shift in center of pressure divided by the assumed position of the center of pressure. Incorporating this factor into equations 16 and 17 we find:

$$F_3 = C_s q A \left(\frac{m+x}{l+m} \right) \quad \text{equation 18}$$

$$F_4 = C_s q A \left(\frac{l+x}{l+m} \right) \quad \text{equation 19}$$

where x is the possible change in dimension l or m due to a shift in center pressure.

Equations 18 and 19 define the maximum lateral load in the mooring points - including an allowance for normal center of pressure shifts.

Side Wind Forces - Vertical Plane:

The free-body diagram in Figure 6 illustrates the forces involved in exerting rolling moments due to a side wind. F_3 , F_4 , D_3 have been defined in equations 15, 16 and 17. The force L_3 is the lift exerted on the semi-span by a side wind and is given as:

$$L_3 = C_l' q S' \quad \text{equation 20}$$

A vertical force, T_3 , will be required for equilibrium only when the lift and drag forces (L_3 and D_3) are sufficiently large to cause the ground reaction at the closest main landing gear to become zero. In this case, the aircraft will be tipping or rolling about on axis through the ground contact points of the second main landing gear wheel and the tail wheel. Under this condition, the following formula can be derived:

$$T_3 = \frac{L_3 [(v+p) \cos \Theta - (c+t) \sin \Theta]}{(p+n) \cos \Theta - (c+j) \sin \Theta} - W \frac{[p \cos \Theta - C \sin \Theta]}{(p+n) \cos \Theta - (c+j) \sin \Theta} + \frac{D_3 \left[\frac{le+lm}{l+m} - s \right] + T_4 g \sin \Theta}{(p+n) \cos \Theta - (c+j) \sin \Theta} \quad \text{equation 21}$$

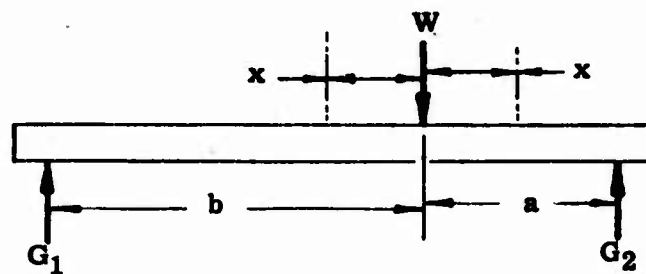


FIGURE 5

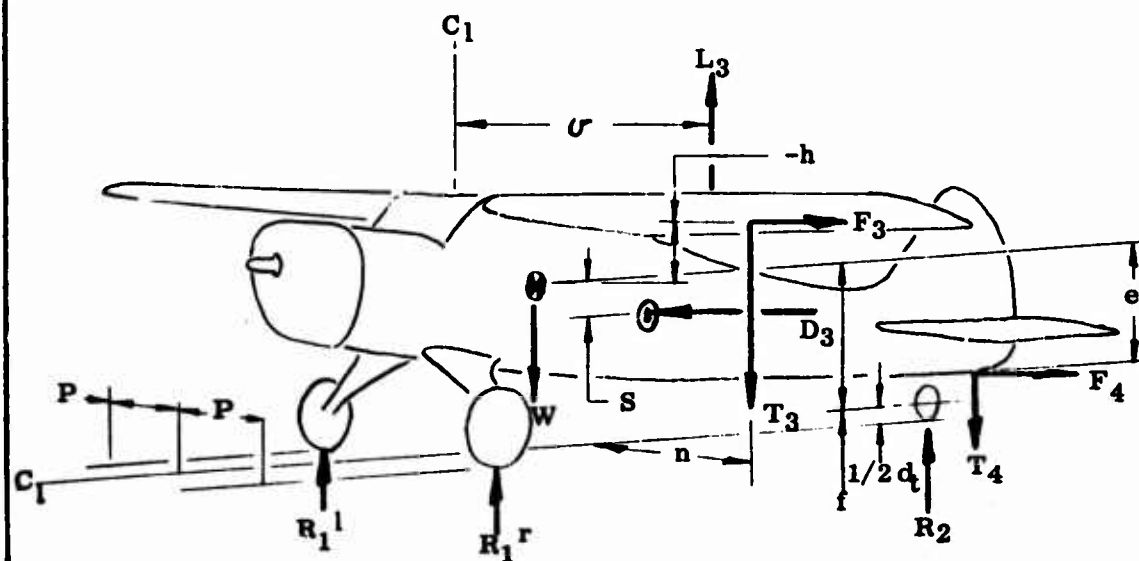


FIGURE 6

It is noted that a vertical force T_4 near the auxiliary landing gear can increase the required vertical force T_3 near the main landing gear. Only if this force, T_4 , acts at a point between the auxiliary and main landing gear can it decrease the required main landing gear mooring point's vertical force.

Since the mooring point near the auxiliary landing gear is normally not between the main and auxiliary landing gears but often coincident with the auxiliary landing gear, it can reasonably be assumed that the vertical force T_4 is merely a function of the horizontal force F_4 and the angle the cable makes with the ground. Thus:

$$T_4 = F_4 \tan \alpha_4 \quad \text{equation 22}$$

where α_4 is the angle of the tie-down cable to the ground projected into a lateral plane.

V. ANALYSIS OF MAXIMUM FORCES AT MOORING POINTS

Auxiliary Mooring Point (the mooring point near the auxiliary landing gear): - The maximum forces in each of three mutually perpendicular planes have been defined for the auxiliary mooring point by the following equations:

$$F_2 = C_d q S \quad \text{equation 11}$$

$$T_2 = \frac{C_d q S e - C_l q S (c - a) - W (c)}{b + c + g} \quad \text{equation 10, 11 and 13}$$

$$F_4 = C_s q A \left(\frac{1 + x}{1 + m} \right) \quad \text{equation 19}$$

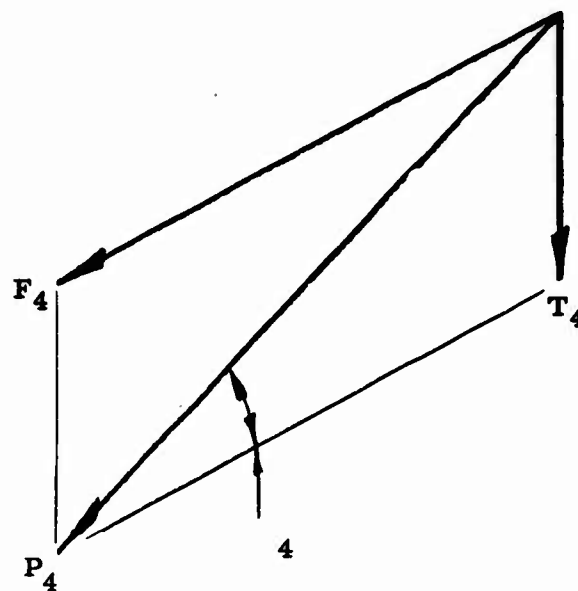
$$T_4 = F_4 \tan \alpha_4 \quad \text{equation 22}$$

From Figure 7 (b), it can be seen that P_2 is the minimum single cable tension necessary to maintain equilibrium against a tail wind and that β_2 is the optimum angle the cable should make with the ground.

$$P_2 = \sqrt{(F_2)^2 + T_2^2} \quad \text{equation 23}$$

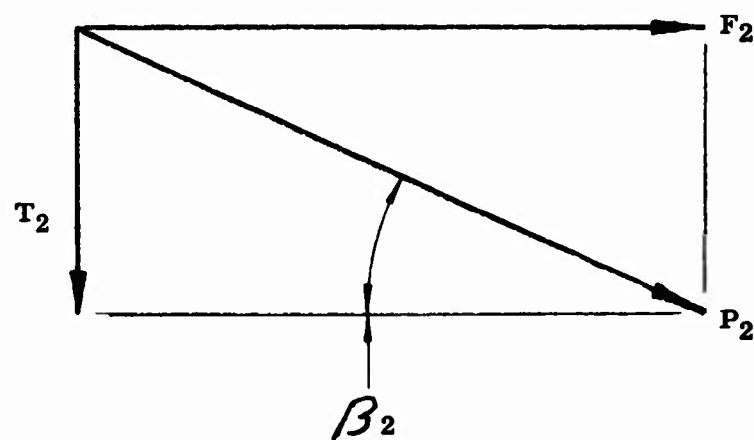
$$\beta_2 = \tan^{-1} \frac{T_2}{F_2} \quad \text{equation 24}$$

From Figure 7 (a) and Equation 23, it can be seen that P_4 and T_4 is a result of F_4 and an angle α_4 . Ideally, the angle α_4 is zero. However, an angle must be selected, and it should be as small as is practical. It must also be noted that a cable tension, equal and opposite to P_4 is required for an equal and opposite side wind.



LATERAL PLANE

Figure 7 a



LONGITUDINAL PLANE

Figure 7 b

These necessary cable tensions can be achieved through two cables at some optimum angle on each side of the plane of symmetry. Under this condition each cable would be required to develop the full forces necessary against a side wind but only half the forces necessary against a tail wind.

From Figure 8 (a) and 8 (b), the magnitude of each cable tension and its angular position with the plane of symmetry and with the ground, which is necessary to produce the tensions P_4 & $1/2 P_2$, can be determined.

For convenience let $T_4 = T_2/2$. Then: equation 25

$$\beta_2 = \tan^{-1} T_2/F_2 \quad \text{equation 24}$$

$$\alpha_4 = \tan^{-1} T_2/2 F_4 \quad \text{equation 26}$$

$$P_r = \frac{1}{2} \sqrt{4F_4^2 + F_2^2 + T_2^2} = \frac{F_2}{2 \cos \gamma_a \cos \int_a} \quad \text{equation 27}$$

$$\int_a = \tan^{-1} \frac{2 F_4}{F_2} \quad \text{equation 28}$$

$$\gamma_a = \tan^{-1} \frac{T_2}{(4F_4^2 + F_2^2)^{1/2}} \quad \text{equation 29}$$

Thus a minimum cable load of P_a will be achieved with a cable placed at an angle \int_a to the plane of symmetry and an angle γ_a to the horizontal at the auxiliary mooring point.

Main Mooring Points (Mooring Points Near the Main Landing Gear)

The maximum forces in each of three planes have been defined for a main mooring point by the following equations:

$$F_1' = \frac{1}{2} C_d q S \quad \text{equation 7}$$

$$T_1' = \frac{C_l q S (a + b) - W(b) + C_d q S h}{2(b - j)} \quad \text{equation 3, 4 and 8}$$

$$F_3 = C_s q A \left(\frac{m + x}{1 + m} \right) \quad \text{equation 18}$$

$$T_3 = C_l' q S' \frac{[(v + p) \cos \Theta - (c + t) \sin \Theta] - W[p \cos \Theta - c \sin \Theta]}{(p + n) \cos \Theta - (c + j) \sin \Theta} +$$

$$\frac{C_s q A \cos \Theta \left[\frac{el + hm}{1 + m} - s \right] + T_4 g \sin \Theta}{(p + n) \cos \Theta - (c + j) \sin \Theta} \quad \text{equation 14, 20, 21}$$



The necessary single cable tension which is required to develop forces F_1' , T_1' , F_3 and T_3 can now be calculated.

Referring to Figure 9 (b):

$$\alpha_3 = \tan^{-1} \frac{T_3}{F_3} \quad \text{equation 30}$$

$$P_3 = \frac{F_3}{\cos \alpha_3} = \frac{T_3}{\sin \alpha_3} = \sqrt{F_3^2 + T_3^2} \quad \text{equation 31}$$

Referring to Figure 9 (a):

$$\beta_1 = \tan^{-1} \frac{T_1'}{F_1'} \quad \text{equation 32}$$

$$P_1 = \frac{F_1'}{\cos \beta_1} = \frac{T_1'}{\sin \beta_1} = \sqrt{(F_1')^2 + (T_1')^2} \quad \text{equation 33}$$

where α_3 and β_1 are the optimum angles, with the horizontal, that cables parallel to the lateral and longitudinal planes, respectively, would have to make to provide a minimum cable stress.

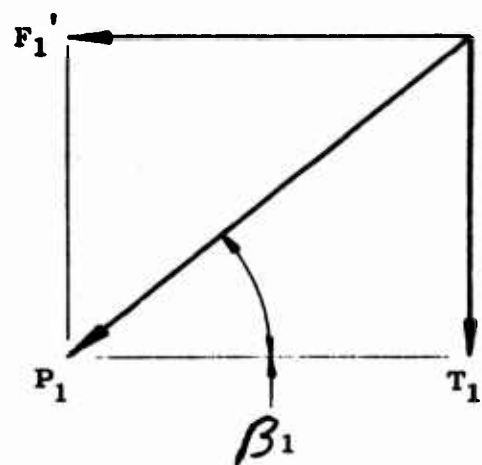
Referring to Figure 10, and defining one cable which can produce the necessary lateral, longitudinal and vertical forces, we have:

$$\tan \int_m = \frac{\tan \beta_1}{\tan \alpha_3} \quad \text{equation 34}$$

$$\tan \gamma_m = \frac{\sin \alpha_3 \sin \beta_1}{\sqrt{\sin^2 \alpha_3 + \sin^2 \beta_1 - 2 \sin^2 \alpha_3 \sin^2 \beta_1}} \quad \text{equation 35}$$

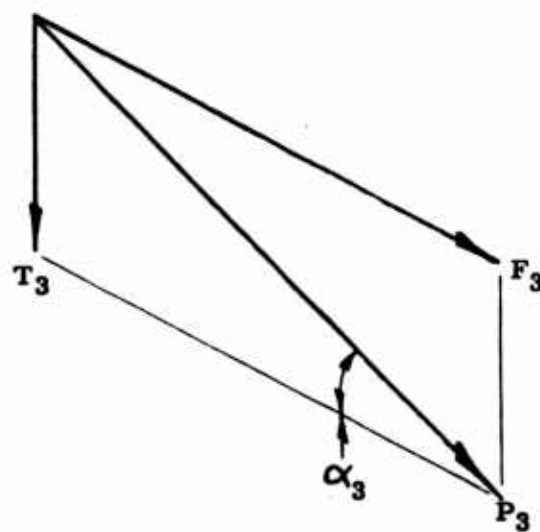
Where \int_m is the angle of the cable with respect to the aircraft's plane of symmetry and γ_m is the angle of the cable with respect to the horizontal at each main mooring point. Having determined the angular positions (\int_m and γ_m) of the optimum cable, we can now determine the actual cable tension.

Referring to Figure 11 (a) the maximum horizontal component of the cable tension can be determined. Having determined the maximum horizontal component of the cable tension, the actual cable tension can be found.



LONGITUDINAL PLANE

Figure 9 a



LATERAL PLANE

Figure 9 b

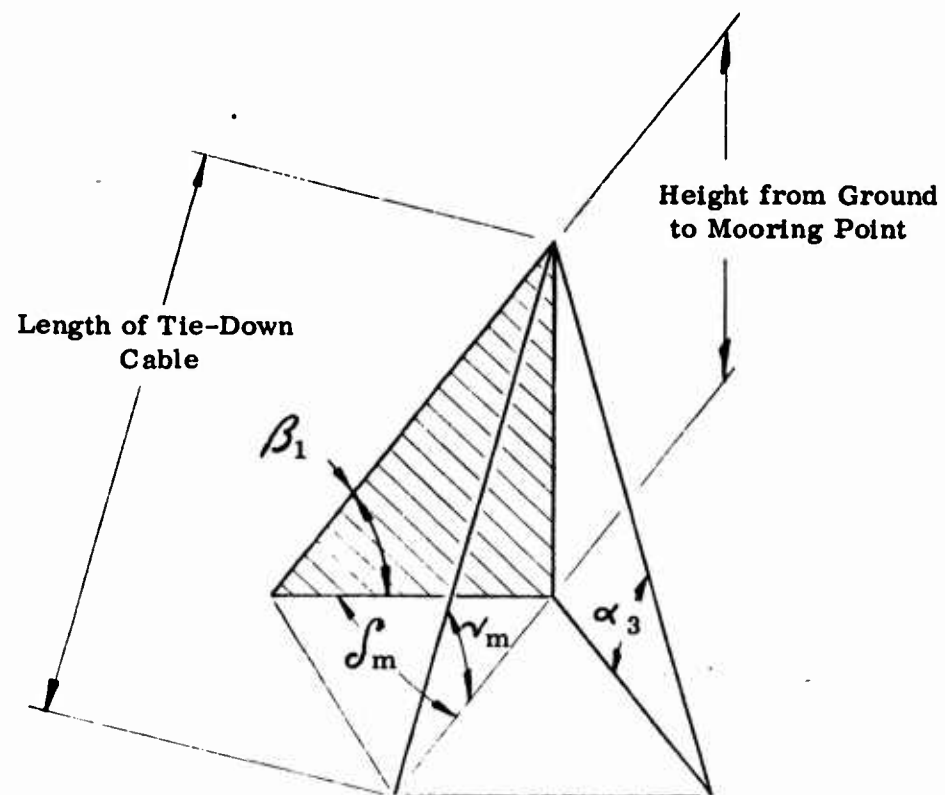


FIGURE 10

Referring to Figure 11 (b):

$$P_{\max} = \frac{Ph_{\max}}{\cos \gamma_m} = \frac{F_3}{\sin \gamma_m \cos \gamma_m} \text{ or } \frac{F_1'}{\cos \gamma_m \cos \gamma_m}$$

whichever is greater.

equation 36

VI. SUMMARY OF GENERAL ANALYSIS:

An aircraft requires a minimum of three mooring points. Two of these mooring points called main mooring points, are spaced equal distances on opposite sides of the plane of symmetry and in the vicinity of the main landing gear. The third or auxiliary mooring point is located in the plane of symmetry and in the vicinity of the auxiliary landing gear.

In some craft, it may not be practical to locate the auxiliary mooring point in the plane of symmetry for structural reasons. In those cases, this mooring point should then be separated into two mooring points equal distances on opposite sides of the plane of symmetry but at the same position forward or aft of the center of gravity.

Considering the three mooring point system, the auxiliary mooring point should be tied to the ground through two cables each making an angle of γ_a on opposite sides of the plane of symmetry and an angle γ_a to the ground.

The maximum cable tension that will be required of each cable will then be, P_a :

$$P_a = \frac{1}{2} \sqrt{4F_4^2 + F_2^2 + T_2^2} = \frac{F_2}{2 \cos \gamma_a \cos \gamma_a} \quad \text{equation 26}$$

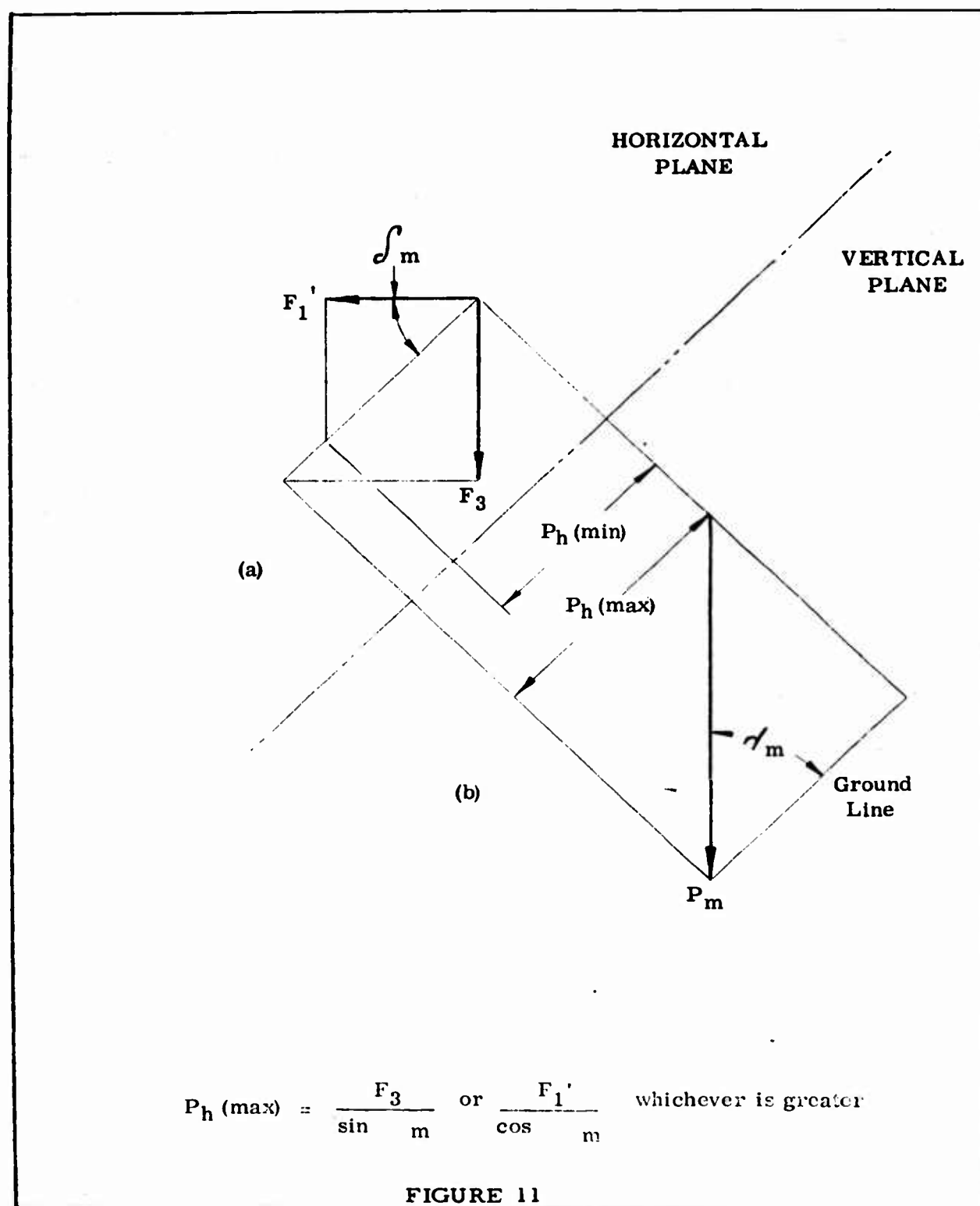
$$\text{where } F_4 = C_s q A \left(\frac{1+x}{1+m} \right) \quad \text{equation 19}$$

$$F_2 = C_d q S \quad \text{equation 11}$$

$$T_2 = \frac{C_d q S e - C_l q S (c - a) - Wc}{b + c + g} \quad \text{equation 10, 11, 13}$$

$$T_4 = F_4 \tan \alpha_4 = T_2/2 \quad \text{equation 22, 25}$$

$$\tan \gamma_a = \frac{T_2}{\sqrt{4F_4^2 + F_2^2}} \quad \text{equation 29}$$



$$\tan \angle_a = \frac{2F_4}{F_2} \quad \text{equation 28}$$

If this single mooring point is separated into two mooring points, then the two tie-down cables described above should be separated, tying one cable at each of the mooring points.

At each of the two main mooring points one cable is required to tie to the ground. The maximum tension in this cable will be P_m :

$$P_m = \frac{F_3}{\sin \angle_m \cos \angle_m} \quad \text{or} \quad \frac{F_1'}{\cos \angle_m \cos \angle_m} \quad \text{whichever is greater} \quad \text{equation 36}$$

where

$$F_1' = \frac{1}{2} C_d q S \quad \text{equation 7}$$

$$F_3 = C_s q A \left(\frac{m+x}{1+m} \right) \quad \text{equation 18}$$

$$\tan \angle_a = \frac{\sin \alpha_3 \sin \beta_1}{\sqrt{\sin^2 \alpha_3 + \sin^2 \beta_1 - 2 \sin^2 \alpha_3 \sin^2 \beta_1}} \quad \text{equation 35}$$

$$\tan \angle_a = \frac{\tan \beta_1}{\tan \alpha_3} \quad \text{equation 34}$$

$$\tan \alpha_3 = T_3 / F_3 \quad \text{equation 30}$$

$$\tan \beta_1 = T_1' / F_1' \quad \text{equation 32}$$

$$T_3 = C_1' q S' \left[\frac{(v+p) \cos \Theta - (c+t) \sin \Theta}{(p+n) \cos \Theta - (c+j) \sin \Theta} \right] - W \left[\frac{p \cos \Theta - c \sin \Theta}{(p+n) \cos \Theta - (c+j) \sin \Theta} \right] +$$

$$\frac{C_s q A \cos \Theta \left[\frac{el+hm}{1+m} - s \right] + T_4 g \sin \Theta}{(p+n) \cos \Theta - (c+j) \sin \Theta} \quad \text{equation 14, 20, 21}$$

$$T_1' = \frac{C_1 q S (a+b) - Wb + C_d q S h}{2(b-j)} \quad \text{equation 3, 4, 8}$$

$$\tan \Theta = \frac{p}{b + c}$$

By definition

From the above, it can be seen that \int_m and γ_m as well as \int_a and γ_a will define the optimum tie-down pattern for any particular aircraft.

It can also be seen that the forces F_4 , F_2 , T_2 define the horizontal and vertical forces that a single auxiliary mooring point must be capable of withstanding, and that F_1' , T_1' , F_3 and T_3 define the horizontal and vertical forces which will be developed at each of the main mooring points.

Tricycle Landing Gear

It can also be shown that the above analysis applies to the larger tricycle landing gear aircraft. In making the application, however, one must carefully watch the above sign convention. That is, what is considered a head wind above would be considered a tail wind for a tricycle landing gear craft and the lift force would be the negative of that illustrated. Similarly what is considered a tail wind above would be a head wind for a tricycle landing gear craft and again the lift force shown would be the negative of the actual lift force. Also, dimensions such as j , g , a , etc., may show a sign reversal.

For clarification, the following sketches (Figures 12 through 15) and formulae are given as applied to a tricycle landing gear:

Head Wind:

$$F_2 = D_2 = C_d q S \quad \text{same as equation 11}$$

$$T_2 = \frac{F_2 (e) + L_2 (c - a) - Wc}{b + c + g} \quad \begin{array}{l} \text{same as equation 13} \\ \text{except } L_2 = -L_2 \end{array}$$

Tail Wind:

$$F_1 = D_1 = C_d q S \quad \text{same as equation 4}$$

$$T_1 = \frac{F_1 h - L_1 (a + b) - W(b)}{b - j} \quad \begin{array}{l} \text{same as equation 6} \\ \text{except } L_1 = -L_1 \end{array}$$

$$F_1' = \frac{1}{2} F_1 = 1/2 C_d q S \quad \text{same as equation 7}$$

$$T_1' = \frac{1}{2} T_1 = \frac{F_1 h - L_1 (a + b) - W(b)}{2(b - j)} \quad \begin{array}{l} \text{same as equation 8} \\ \text{except } L_1 = -L_1 \end{array}$$

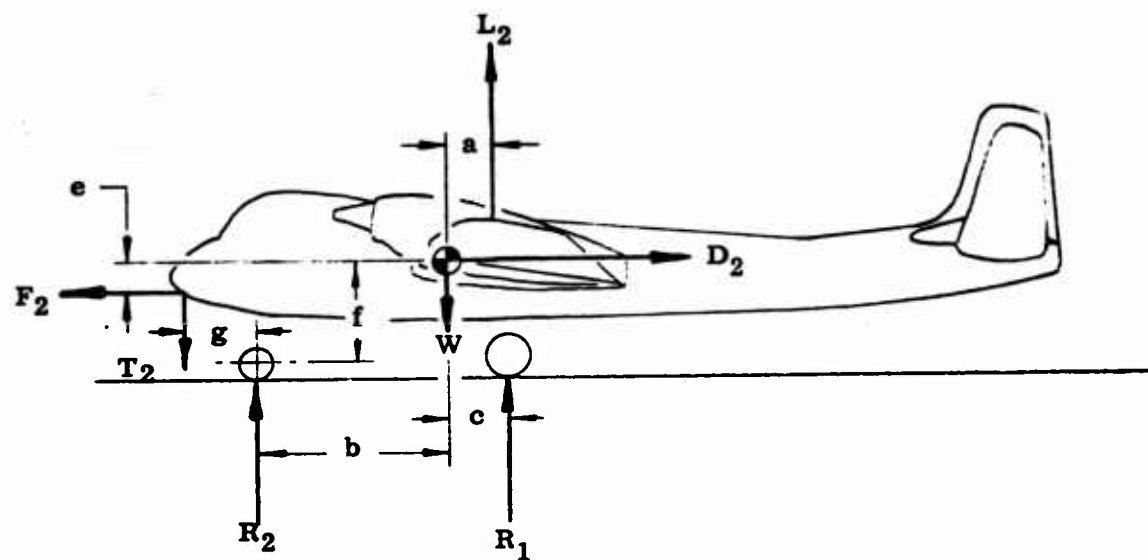


FIGURE 12

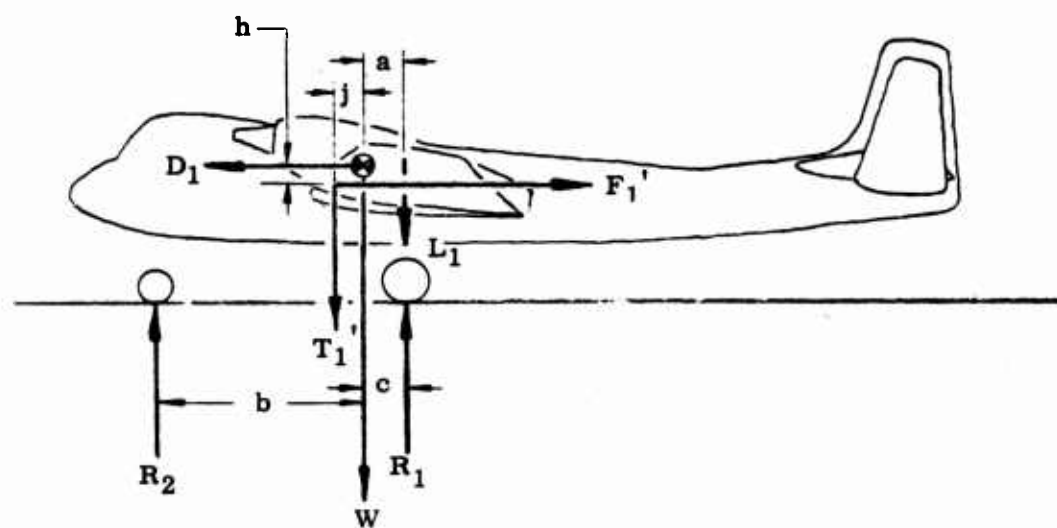


FIGURE 13

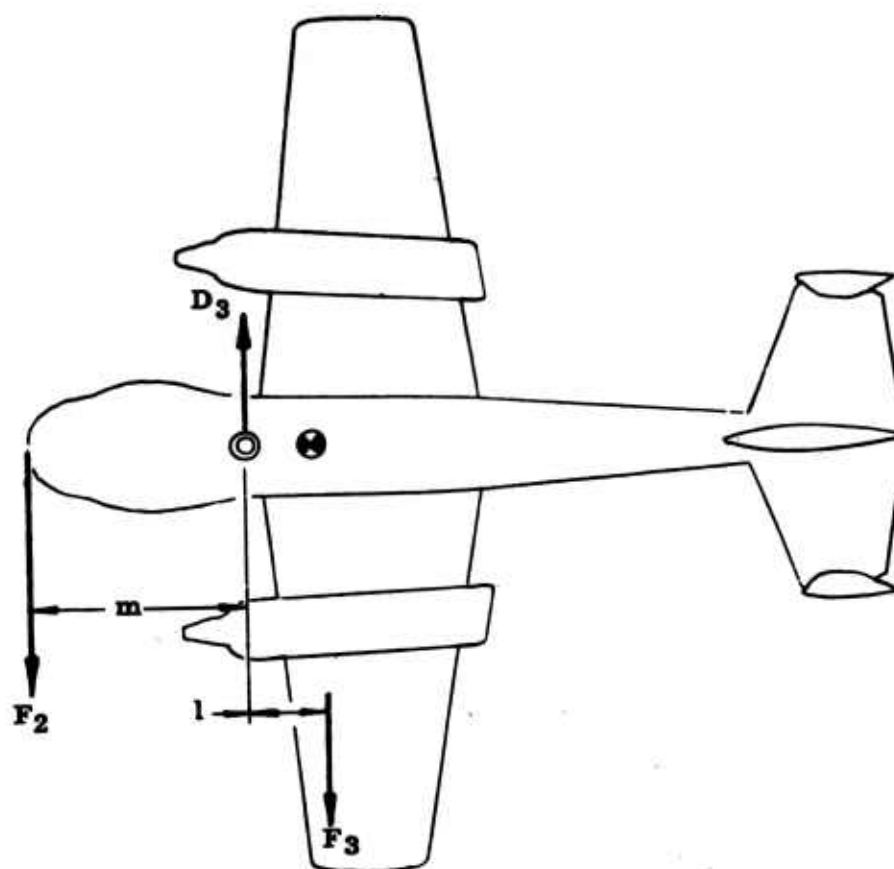


FIGURE 14

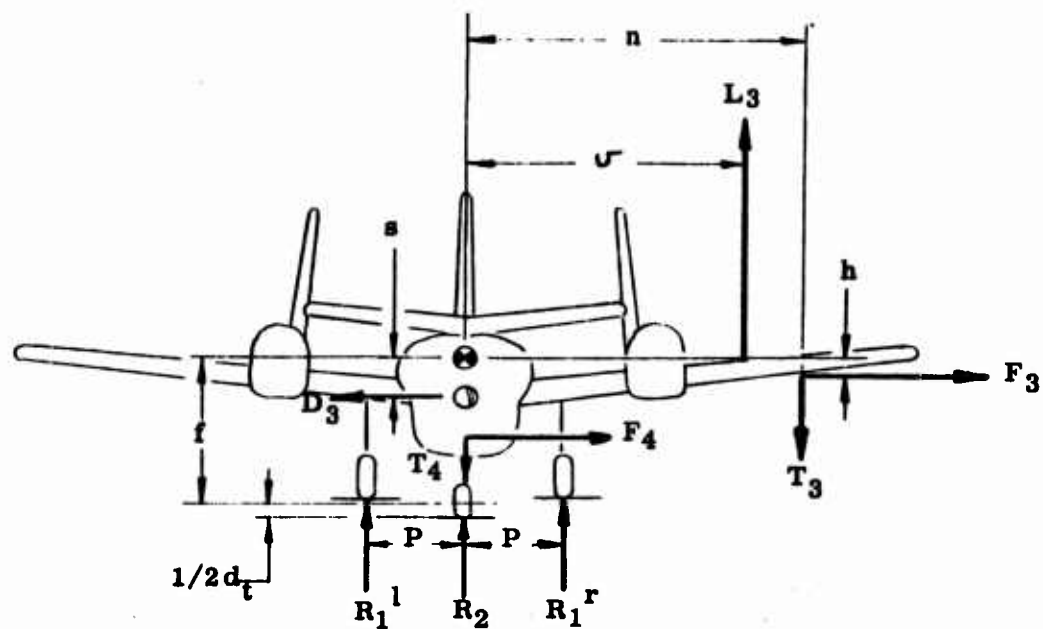


FIGURE 15

Side Wind - Horizontal Plane

$$D_3 = F_3 + F_4 = C_s q A$$

same as equation 15

$$F_3 = C_s q A \left(\frac{m + x}{1 + m} \right)$$

same as equation 18

$$F_4 = C_s q A \left(\frac{1 + k}{1 + m} \right)$$

same as equation 19

Side Wind - Vertical Plane:

$$T_3 = \frac{L_3 \left[(v + p) \cos \Theta - (c + j) \sin \Theta \right] + D_3 \cos \Theta \left[\frac{le + hm}{1 + m} - s \right] - W (p \cos \Theta - c \sin \Theta + \frac{T_4 g \sin \Theta}{(n + p) \cos \Theta - (c + j) \sin \Theta})}{(n + p) \cos \Theta - (c + j) \sin \Theta}$$

same as equation 21

From the above formulae, it can easily be shown that the optimum cable angles and loads are the same as given above in "Summary of General Analysis" except that C_1 is considered negative for a tricycle landing gear craft.

VII. DETAILED ANALYSIS OF AIRCRAFT

As with any transition from theoretical to practical, certain assumptions must be made. The assumptions made for the following analysis are presented here.

Location of Center of Pressure of a Side Wind

The center of pressure of a flat plate, normal to the wind would be at the centroid of the flat plate area. Since an aircraft is not flat, the center of pressure is not necessarily at the centroid of the flat projected area.

Considering a typical fuselage, the side of the forward section is generally flatter than the side of the aft section. Thus the forward section would be responsible for a larger percent of the total wind force — or the center of pressure would be forward of the centroid of the projected side area.

From the above reasoning and from experimental data made available from Sikorsky Aircraft, the center of pressure of typical fuselages is assumed to be at a fuselage station where 40% of the projected fuselage area is forward. It is also assumed to be at the same level, above ground, as the center of gravity.

For lack of more authoritative information, the center of pressure on a wing in a side wind is assumed to be at the centroid of its projected area. This is reasonable since the wing does approximate a flat plate.

Thus for helicopters with typical fuselages, the center of pressure is located at a fuselage station where approximately 40 % of the side area is forward. For helicopters with unusual fuselages, H-21 for example, the side area is approximated by flat plate areas each of which has a resultant wind force acting at the respective area centroid. Relationships between each of these wind forces are estimated based upon the flatness or roundness of the respective represented areas. Resolving these wind forces into one resultant force equal to the total drag force, locates the center of pressure of the total drag force.

For fixed wing aircraft, the center of pressure of the fuselage is approximated as described above and is then further resolved with drag force on the wing, which is assumed to act at the centroid of the projected wing area. The magnitude of the fuselage drag force and wing drag force are proportioned by the ratio of projected wing area to projected fuselage area. These forces are then resolved into one force equal to the total aircraft drag and located at the center of pressure.

Location of Wing Lift Force in Head or Tail Wind:

For lack of complete information, the location of the center of pressure on the wing is assumed at approximately one-quarter chord at the mid-point of the semi-span. The assumption is made for both head winds and tail winds.

Dynamic Pressure

Dynamic pressure is calculated as $\frac{\rho v^2}{2}$ and equals 18.7 psf or .13 psi, assuming standard air. This value is construed to be " $C_d q$ " or " $C_g q$ " and is very much in line with Paragraph 3.5.4.3 of MIL-A-8629 (Aer) as well as wind tunnel data which was made available by Sikorsky Aircraft.

An arbitrary value of " q " equal to .219 psi was selected from information supplied by aircraft manufacturers on Lift and Drag coefficients and the corresponding Lift and Drag forces of their respective craft. From this drag coefficients for all the crafts were approximated.

Lift on Semi-Span during Side Wind

Drag forces and lift forces are normally considered to act at the center of gravity and are attended by a pitching moment. Were the aircraft not

symmetrical, there would also be a yawing moment. In a side wind, rolling and yawing moments are involved. However, considering the drag force in a side wind to act at the center of pressure provides the moment arms of the yawing and rolling moments. Due to the manner of approximation of the location of the center of pressure, it is assumed that the moment arms for yawing and rolling moments include the torque effects of lift or the semi-span. It is also assumed that the actual lift force is negligible. Thus C_L , v and t as defined in the above general analysis all become zero. This assumption renders a vertical tension at the main mooring point somewhat smaller than is ideally required. However, it will be shown that the vertical component of the tie-down cable which exerts the necessary horizontal restraining force is much larger than the required vertical tension.

VIII. SPECIFIC ANALYSIS

Table I gives all of the required data that is available for each of the Army aircraft considered under this study. Data given by the manufacturers is distinguished from data that has been projected or assumed.

Table II gives all the calculated horizontal and vertical loads and optimum angles as calculated from data in Table I.

Table III gives cable tensions calculated from the required horizontal and vertical loads and optimum angles or assumed angles where the optimum angle is zero.

IX. SUMMARY OF DETAILED ANALYSIS

From the above calculated figures, it can be seen that tie-down cables need not apply vertical components of tension to maintain equilibrium. Thus, the derived formulae for the four vertical components (T_1 , T_2 , T_3 , and T_4) of force at each mooring point need no further consideration.

Since no vertical force is required at the various mooring points, the optimum angle which a tie-down cable makes with the ground must be "zero". This is not practical, and some arbitrary angle must be selected based upon the allowable vertical force at the mooring point, allowable stress in and length of the cable and holding power of the ground anchor. Cable loads shown in Table III above assumed an arbitrary angle of 45° with the ground at the main mooring point. Decreasing this angle will lengthen the required cable, decrease the cable tension, and possibly allow use of fewer ground anchors.

Calculation of the necessary horizontal forces at the mooring points is dependent solely upon the drag force of a wind, and the location of the center of pressure of the wind. Due to symmetry, the center of pressure in a head

TABLE I
DATA REQUIRED FOR ANALYSIS OF HORIZONTAL AND VERTICAL FORCES
AT MOORING POINTS ON AIRCRAFT

DESIG.	TYPE	MADE BY	DIMENSIONS																	HEAD & TAIL WIND LOADS			SIDE WIND LOADS	
			a (in)	b (in)	c (in)	d (in)	e (in)	f (in)	g (in)	h (in)	i (in)	j (in)	k (in)	l (in)	m (in)	n (in)	p (in)	q (in)	r (in)	s (in)	C _d	C _e	A (sq. ft.)	
L-23	Tricycle Landing Gear - Midwing	Beech Aircraft	7	107	22	7	- 4	7	- 5	7	7	7	7	7	7	76.5	7	7000	7	7	7	7	7	7
H-13	Helicopter with Skids	Bell Helicopter	0	7	7	7	0	7	7	7	7	7	7	7	7	45	7	7	7	7	7	7	7	7
HUI-A	Helicopter with Skids	Bell Helicopter	0	27.2	43.2	7	35	7	- 44	- 44	44	35	25	25	25	50.2	0	5725	0	348	7,700	456	26100	0
L-19	Conventional Landing Gear - Highwing	Cessna Aircraft	7	7	7	7	7	7	7	7	7	7	7	7	7	40.9	7	2400	7	7	7	7	7	7
L-20	Conventional Landing Gear - Highwing	De Havilland Aircraft	0-6	237	34	60.6	0	23	0	- 50.7	186.3	219	126.1	61	1.51	5100	153	56,000	154	21310	154	21310	154	21310
U-1A	Conventional Landing Gear - Highwing	De Havilland Aircraft	0	300	35	58.6	0	40	12	- 78	210	219	147	67	- 2.27	6000	112	54,000	112	54,000	112	54,000	112	54,000
YAC-1	Tricycle Landing Gear - Midwing	De Havilland Aircraft	-20	270	36	---	---	---	---	-149.4	440.4	219	---	139	---	26000	178	131,000	184	167500	184	167500	184	167500
AOI-A	Tricycle Landing Gear - Midwing	Grumman Aircraft	0-22	113.5	26.7	48.1	0	8.5	-26.85	36.5	103.8	219	152	55	---	9400	303	6,160	303	47,000	304	37700	304	37700
H-23	Helicopter with Skids	Miller Aircraft	0	22.5	59.0	35.7	0	35.7	59.0	46	34.5	219	40	45	0	2137	0	345	4,150	345	4,150	345	4,150	345
H-19	Helicopter with 4-wheels	Bikorsky Aircraft	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
H-34	Helicopter with 3-wheels	Bikorsky Aircraft	0	301	36.4	36.4	- 34	- 12	- 27.4	63.4	231	219	34	72	- .00	11067	0	365	8,000	365	8,000	365	8,000	365
H-37	Helicopter with 3-wheels	Bikorsky Aircraft	0	406	37.3	78.5	11.0	59	- 37.3	37.3	41.7	219	120	127	0	36059	0	365	20,700	365	20,700	365	20,700	365
H-21	Helicopter with 3-wheels	Vernol Aircraft	0	251	45.1	34.7	7.8	5.0	- 5.2	66.5	240	219	37	90	0	13276	0	345	10,000	345	10,000	345	10,000	345
YHC-1	Helicopter with 3-wheels	Vernol Aircraft	0	189	109	58.3	8.9	31.4	-106.4	112	195	219	79.6	63.5	0	16600	0	345	15,000	345	15,000	345	15,000	345

* These figures are not given by the corresponding manufacturer of the aircraft. They have been projected or approximated for the purpose of this report.

^① Symbols are defined elsewhere in this report.

TABLE II

CALCULATED HORIZONTAL & VERTICAL MOORING POINT FORCES & OPTIMUM ANGLES
OF SPECIFIC ARMY AIRCRAFT

	FORMULA ^①	L-20	U-1A	AO1-A	H-23	H-34	H-37	H-21	YEC-1	REMARKS
F_1'	$1/2 C_d q S$	485 #	600 #	242.5 #	165 #	320 #	1300 #	423.5 #	505 #	
F_2	$C_d q S$	970 #	1320 #	525 #	330 #	640 #	3180 #	847 #	1010 #	
F_3	$C_d q A \left(\frac{W}{1+W} \right)$	2200 #	4000 #	3000 #	380 #	4600 #	3520 #	6000 #	4600 #	
F_4	$C_d q A \left(\frac{1+W}{1+W} \right)$	695 #	1570 #	1450 #	514 #	1262 #	3150 #	1725 #	2620 #	
T_1	$\frac{C_d q S (a + b - C_d q S h - W b)}{2 (b - 1)}$	0	0	0	0	0	0	0	0	All calculated vertical restraining forces yielded negative values, indicating that pitch and roll moments due to winds at 75 knots do not overcome the aircraft weight
T_2	$\frac{C_d q S b - C_d q S (c - a) - W c}{b - c - g}$	0	0	0	0	0	0	0	0	
T_3	$\frac{C_d q A \cos \phi \left[\frac{b - h m}{1 + m} - a \right] + T_2 g \sin \phi - W \left[\rho \cos \phi - c \sin \phi \right]}{(b - m) \cos \phi - (c - 1) \sin \phi}$	0	0	0	0	0	0	0	0	
T_4	$1/2 T_2$	0	0	0	0	0	0	0	0	
$\tan \phi_s$	$2 F_4 / F_2$	1.432	2.38	5.52	3.11	3.94	1.96	4.07	5.58	Optimum angles to planes of symmetry
$\tan \beta_1$	T_1' / F_1'	0	0	0	0	0	0	0	0	
$\tan \alpha_3$	T_3 / F_3	0	0	0	0	0	0	0	0	
$\tan \phi_m$	$\tan \beta_1' \tan \alpha_3$ when $T_1' & T_3 \rightarrow 0 \tan \phi_s \rightarrow F_3 / F_1'$	0	0	0	0	0	0	0	0	Optimum angles to planes of symmetry
$\tan \alpha_s$	$2 T_2 / \sqrt{4 F_4^2 + T_2^2}$	4.54	6.16	13.72	2.31	14.4	2.21	14.2	9.28	
$\tan \alpha_m$	$\frac{2 T_2 \sqrt{4 F_4^2 + T_2^2}}{\sin \alpha_3 \sin \beta_1}$	0	0	0	0	0	0	0	0	Optimum angle of tie-down cable with the ground is found to be "zero"

① All symbols are defined elsewhere in this report

② Calculations are made using data shown in Table I

TABLE III. CALCULATED CABLE LOADS AND ANGLES OF SPECIFIC ARMY AIRCRAFT										
		L-20	U-1A	AO1-A	H-23	H-34	H-37	H-21	YHC-1	
$\tan \delta_a$	$\frac{\text{calculated}}{\text{assumed}}$	1.432	2.38	5.52	3.11	3.94	1.98	4.07	5.58	
$\tan \delta_m$	$\frac{\text{calculated}}{\text{assumed}}$	4.54	6.16	13.72	2.31	14.4	2.21	14.2	9.28	
$\tan \delta_a$	$\frac{\text{calculated}}{\text{assumed}} \textcircled{2}$	0	0	0	0	0	0	0	0	
$\tan \delta_m$	$\frac{\text{calculated}}{\text{assumed}}$.135	.043	.337	1.000	.438	.362	.634	.444	
P_a		0	0	0	0	0	0	0	0	
P_m	$\frac{F_2}{2 \cos \delta_a \cos \delta_m}$	855 #	1710 #	1555 #	763 #	1445 #	3740 #	2110 #	3140 #	
	$\frac{F_3}{\cos \delta_m \sin \delta_m} = \frac{F_1}{\cos \delta_m \cos \delta_m} \textcircled{1}$	3200 #	5820 #	5100 #	585 #	6530 #	5440 #	8500 #	6680 #	
	Length of Cable (between points in optimum Tie-Down)	66"	149"	102"	10"	78.5"	53.4"	114"	89"	
<p>① Had vertical forces T_1' and/or T_3 been real values cable force P_f would be the larger of these two quantities. These two quantities are equal only when $T_1' = T_3$</p> <p>② Values of $\tan \delta_a$ were assumed such that the lengths of all tie down cables for any one craft are equal</p> <p>NOTE: If the tangent of the angles δ_m were assumed to be .500, cable loads, P_m would decrease less than 20%</p>										

or tail wind can be assumed to occur at the center of gravity of the aircraft. However, due to lack of symmetry, the center of pressure due to a side wind must be approximated.

Some existing documents assume the center of pressure to be located at that fuselage station which divides the projected normal side area in half: - fore and aft. Wind tunnel data from Sikorsky Aircraft illustrates that this is not true for their helicopters. The data indicates that for Aircraft H-34 and H-37, the center of pressure occurs at that fuselage station which divides the projected normal area approximately 38% fore and 62% aft. Since the general shape of these helicopters does resemble the general shape of a typical light fixed wing craft, a 40 - 60% approximation is used in this report to apply to all aircraft fuselages.

For fixed wing craft, the center of pressure of the fuselage must be resolved with the center of pressure of the wing to approximate the center of pressure of the total craft. However, when possible, additional wind tunnel tests should be conducted on a variety of aircraft shapes to provide more reliable data from which center of pressures can be approximated.

The magnitude of the total drag force due to side winds can be approximated through the following formula:

$$D_s = PA_s$$

where

$$P = .0025V^2$$

A = projected area normal to wind in square feet

V = wind velocity in miles per hour

For head and/or tail winds, where streamlining reduces the drag force, the magnitude of the drag force can be approximated by:

$$D_h = D_t = .6PA_h$$

Distribution of Mooring Points

Where loading permits, only three mooring points should be utilized. These three mooring points should consist of two main mooring points (on opposite sides of the plane of symmetry) at a fuselage station near the main landing gear and an auxiliary mooring point in the plane of symmetry at or near the auxiliary landing gear.

Four tie-down cables should be utilized, one at each main mooring point and two at the auxiliary mooring point, all cables making some angle with the plane of symmetry. The tangent of the angle at each cable is

equal to the ratio of the lateral to longitudinal forces which are required of the cable. The angle of each cable with the ground should be the minimum practical angle so as to keep cable tensions at a minimum.

Where loading is excessive on either the aircraft structure, cable, or ground anchor, the number of mooring points should be increased and distributed rationally so as to minimize this loading, and still conform to the Army's pattern of ground anchors at a permanent parking apron.

Again optimum angles for each tie-down cable with the plane of symmetry must be defined and the minimum practical angle of the cable to the ground must be utilized.

X. DESIGN CRITERIA FOR MOORING POINTS ON ARMY AIRCRAFT

When designing mooring points on an Army aircraft several points must be considered. The most important of these points is the loading at each point.

A three mooring point system is preferred, but often leads to excessive loads for expeditionary ground anchors.

The total horizontal load which is required to restrain against tail wind or head wind equals: -

$$D_h = D_t = (.0025V^2A_h).6$$

against side wind:

$$D_s = .0025V^2A_s$$

where V = wind velocity in miles per hour

A = area of aircraft projected normal to the wind

and must be distributed among a minimum number of mooring points.

The point of action (the center of pressure) of the one resultant drag force in a head wind or a tail wind can be assumed to be coincident with the center of gravity while the location of the center of pressure in a side wind must be approximated.

XI DESIGN EXAMPLE

For an illustrated example, consider the Caribou Aircraft, YAC-1, which was withheld from the specific analysis above. We will assume that this craft has no mooring provisions and must be moored from each of the landing gear as shown below (Figure 16).

For a head wind or tail wind the drag force equals:

$$D = (.0025V^2A) \cdot 6$$

$$V = 86 \text{ miles per hour}$$

$$A = 447 \text{ sq. ft. (planimetered)}$$

$$= .0025(86)^2 447(.6)$$

$$= 4960\#$$

Thus each of the two cables which restrain against either a head wind or a tail wind must exert a horizontal force component ($F_{2/2}$ or F_1') of 2480# (assuming icy terrain and therefore negligible friction).

Assuming a coefficient of friction (μ) between wheels (brakes on) and the ground of .1, the friction force (F_f) equals:

$$F_f = \mu W$$

$$= .1(26000)$$

$$= 2600\#$$

In this case each of the cables would have to exert:

$$\frac{4960 - 2600}{2} = 1180\#$$

For a side wind and assuming the center of pressure to be 149.4 inches aft of the main landing gear (Figure 17):

$$D_s = (.0025V^2A)$$

$$V = 86 \text{ miles per hour}$$

$$= (.0025)86^2(753)$$

$$A = 753 \text{ sq. ft. (planimetered)}$$

$$13900\#$$

Summing moments about the nose wheel, we find the horizontal lateral force component required at the main landing strut (F_3):

$$F_3 = \frac{D_s (440.4)}{(440.4 - 149.4)} =$$

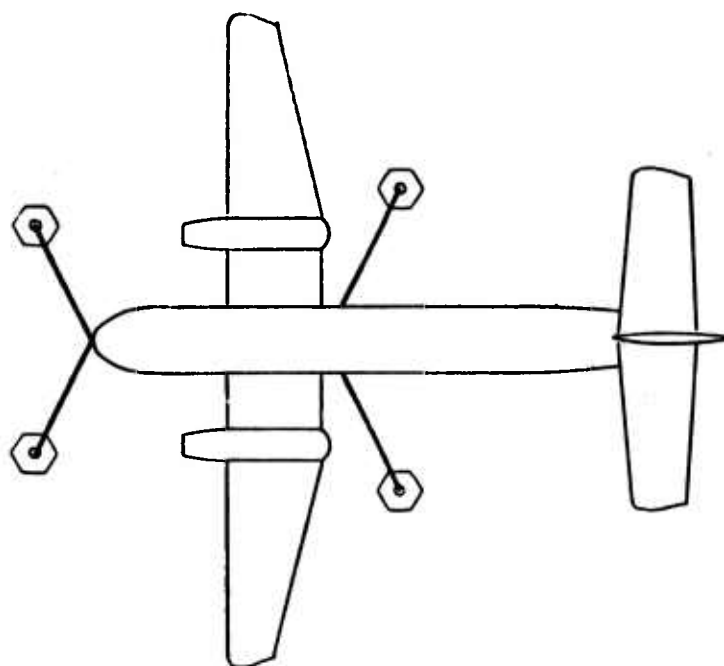


FIGURE 16

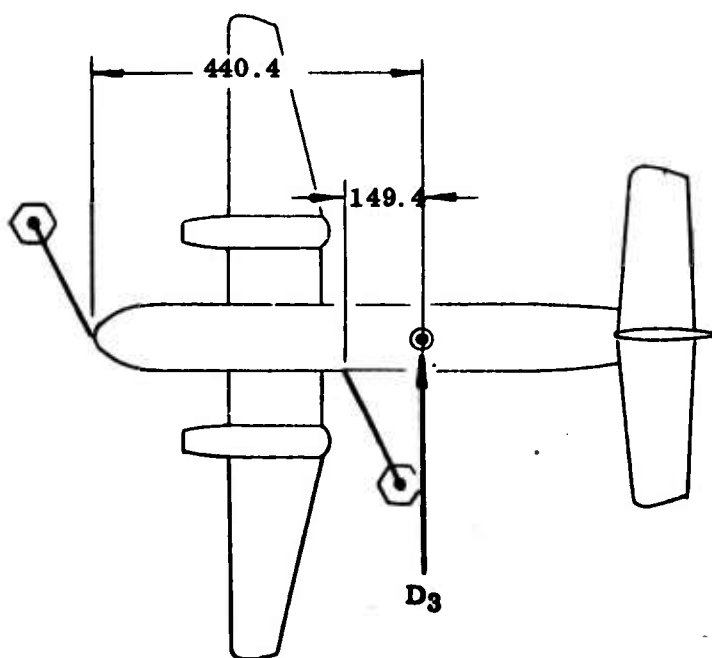


FIGURE 17

$$= 13,900 \frac{(440.4)}{(291)}$$

$$= 21,800\#$$

Summing moments about the main landing gear, we find the horizontal lateral force component required at the nose wheel

$$F_4 = D_s \frac{(149.4)}{(291)}$$

$$= 13,900 \frac{(149.4)}{(291)}$$

$$= 7100\#$$

Again these calculations assume no friction between the ground and the wheels which is reasonable on icy terrain. Assuming the same friction coefficient as above, yielding a 2600# force, and further assuming that it acts completely at the main landing gear, F_3 would be reduced by an almost negligible amount to 19,200 lbs.

It is now obvious that the load must be distributed among other points. For instance, if a tie-down point 440 inches aft of the center of pressure (730 inches aft of the nose wheel or fuselage station 722) the drag load of 13,900 lbs. could then be distributed equally 6,950 lbs. at the nose wheel and at the tail mooring point. Or the load could be rationally distributed between the nose wheel, main landing gear and the tail mooring point such that:

$$\text{Main Landing Gear Force} = 5560\#$$

$$\text{Nose Wheel Force} = 3260\#$$

$$\text{Tail Mooring Force} = 5180\#$$

which is a reasonable loading. The resulting tie-down pattern is shown in Figure 18.

The manufacturer of this particular aircraft has designated five mooring points on the craft: the nose wheel, each of the main landing struts, a point in the plane of symmetry at fuselage station 415 and a second point in the plane of symmetry at fuselage station 755.15. This corresponds closely with the design suggested above except that an extra mooring point at station 415 has been provided.

Cable loads due to a side wind for the given mooring points, neglecting the point at fuselage station 415, are rationalized as being:

Main Landing Gear Force = 5000#

Nose Wheel Force = 3800#

Tail Mooring Force = 5100#

The optimum angle \int for each cable with the plane of symmetry can now be defined as:

$$\tan \int_m = \frac{5000}{2480} = 2.02$$

$$\tan \int_a = \frac{3800}{2480} = 1.53$$

$$\tan \int_t = \frac{5100}{0} = \infty$$

Thus the optimum tie-down pattern is defined for the YAC-1.

Cable lengths required can be established after selection of the angle of each cable with the ground. The four forward cable lengths can be established in the same manner as previously determined--select an arbitrary angle of 45° with the ground for the cables at the main mooring points and determine a cable length. Use this same length to define an angle with the ground for the cables at the auxiliary mooring point. Then use an extra length cable for the tail mooring point due to the extreme height of this mooring point.

Arbitrarily selecting 45° as the angle to the ground for the main tie-down cables and the tail tie-down cables, we can calculate the following quantities:

<u>Location</u>	<u>Cable Tension</u>	<u>Tan \int</u>	<u>Cable Length</u>
Main Mooring Point	7900#	2.02	71.6"
Auxiliary Mooring Point	4970#	1.53	71.6"
Tail Mooring Point	7200#	∞	193"

Thus, the above design example and subsequent check of the actual mooring points, illustrates the loading consideration that a designer must first consider to determine approximate locations of mooring points. After selection of specific, structurally sound locations, a recheck of the

calculations must be made to insure that cable loads have not been made excessive. Then the optimum tie-down pattern and required cable lengths should be specified.

Having determined a minimum number of mooring points and of tie-down cables required for mooring without overstressing the aircraft or the cables is only part of the design effort. Several technical characteristics must be met in the mooring points. These characteristics are presented below.

XII. TECHNICAL CHARACTERISTICS OF MOORING POINTS

Arriving at a reasonable loading in a manner similar to above, the aircraft designer must then consider these characteristics:

- a. Maximum allowable structural stress in aircraft at mooring points versus stresses caused by mooring loads
- b. Angles which tie-down cables should make with plane of symmetry for minimum cable tensions
- c. Angles which tie-down cable can make with ground versus length of cable required and compatibility with Army's standard pattern of ground anchors at a permanent parking apron
- d. Accessibility of mooring points
- e. Effect of mooring point upon aerodynamic performance
- f. Ease of attaching twice the number of normal tie-down cables, whether manila rope, wire rope, cable clamp or hook
- g. Capability of ground anchors to restrain against the required cable tension

XIII. DESIGN CONSIDERATIONS

Application of these characteristics to the mooring pattern suggested in Figure 18 reveals:

- a. Loads are probably compatible with allowable aircraft stresses
- b. Optimum angles for each cable to the plane of symmetry is defined as the angle whose tangent is the ratio of the required lateral force to the required longitudinal force.

c. Angles to the ground of each tie-down cable should be kept at a minimum to:

1. Keep cable tensions at a minimum
2. Keep vertical component of cable tension at a minimum

However, the minimum angle must be limited by the length of tie-down cable and available space.

- d. The designer of the mooring point must make it readily accessible, either fully exposed or readily exposed through a quick opening access door which is properly labeled.
- e. Use of a concealed mooring point and an access door should only be made when use of an exposed mooring point will detract from the aerodynamic performance of the aircraft
- f. Upon establishment of the normal number of tie-down cables required at each mooring point to restrain the aircraft in a 75 knot wind and in an expeditionary status with good soil conditions, clearance must be provided for twice as many tie-down cables at each mooring point to allow adequate mooring under adverse soil and ground anchor conditions.
- g. Sufficient mooring points should be provided so that loads are small enough to allow use of preferably one, but no more than two, ground anchors per tie-down cable in an expeditionary status and under good soil conditions. In the above illustrative example, and assuming a ground anchor is capable of approximately 3000# pull at 45° to the horizontal, approximately 2000# horizontal component:
 1. each nose wheel tie-down cable requires two ground anchors
 2. each of the other four indicated cables must be replaced by two cables tied to three ground anchors (see Figure 19)

For the Caribou, it appears that under expeditionary and good soil conditions the normal number of tie-down cables of each mooring point is (see Figure 19):

Nose Wheel Mooring Point	2 cables
Each Main Landing Gear Mooring Point	2 cables
After Mooring Point	4 cables

From technical consideration "Y" each mooring point will have to provide clearance to attach twice as many as the normal expeditionary number of tie-down cables.

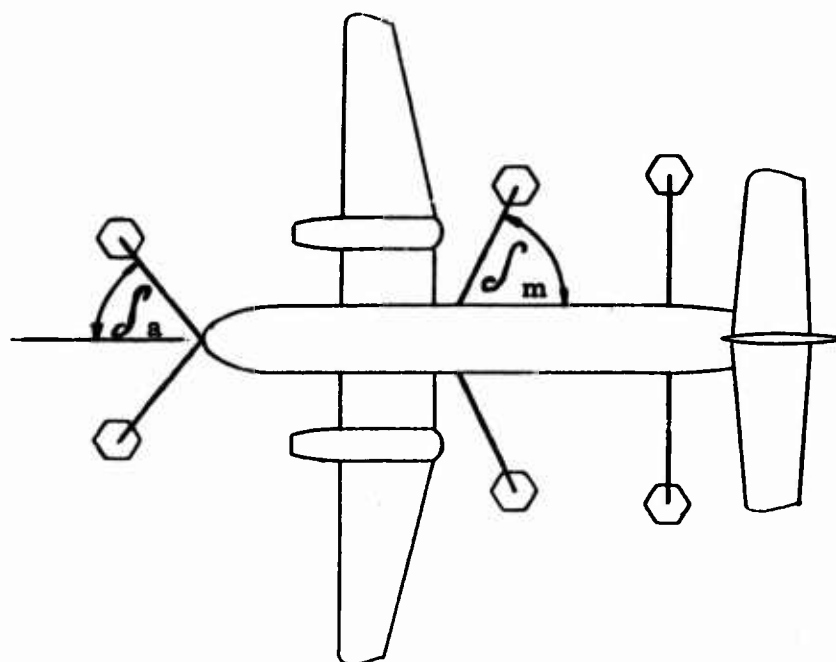


FIGURE 18

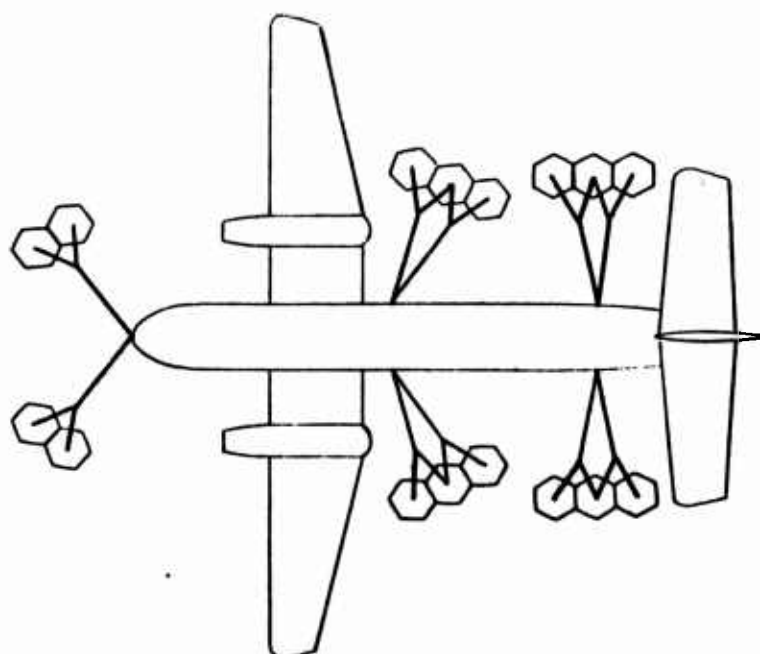


FIGURE 19

At a permanent parking apron where the ground anchors are capable of up to 12,000 or so pounds, the mooring pattern illustrated in Figure 18 should be considered the normal and optimum pattern.

XIV. STANDARD, SINGLE OPTIMUM PATTERN OF GROUND ANCHORS

From comparison of the various optimum patterns of the nine aircraft which have been analyzed, it appears that a layout of permanent ground anchors in an apron and flush with the apron in a four by four foot (4' x 4') square pattern will best suit the Army's variety of aircraft.

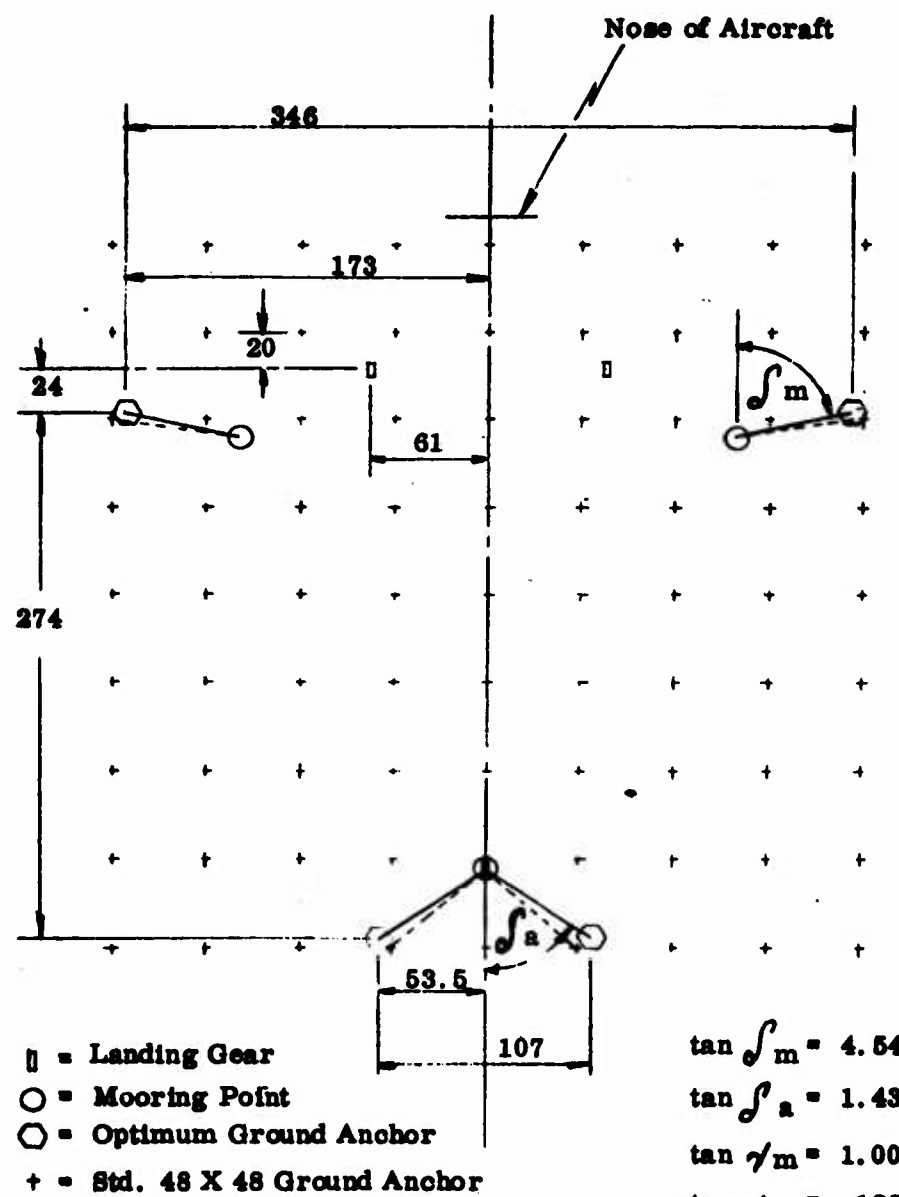
Such a pattern would allow mooring of any of the aircraft at almost any location and in either of two perpendicular positions. It would allow creation of traffic aisles between parked aircraft in accordance with the size of the aircraft being parked. A disadvantage is the great number of ground anchors required and the allied expenses.

Dependent upon the type and number of aircraft normally assigned to any facility, it may be both feasible and desirable to utilize only portions of this 4' X 4' pattern and restrict a certain area to a particular type of craft and include a small area with the full 4' x 4' pattern for use by craft not normally assigned to the facility.

For instance, if a facility normally has U-1A, H-37 and H-23 aircraft only, it may be advantageous to provide a parking aisle for each with only the ground anchors in each aisle that are required for the respective craft, and an area with the full 4' x 4' pattern for tie-down of visiting craft or craft flown in from a high wind area. When doing this, however, all of those selected ground anchors should fit the overall 4' x 4' pattern. Then, if at a later date, additional anchors are required, due to a change of status or mission at the facility, they can be readily installed in a partially existing pattern.

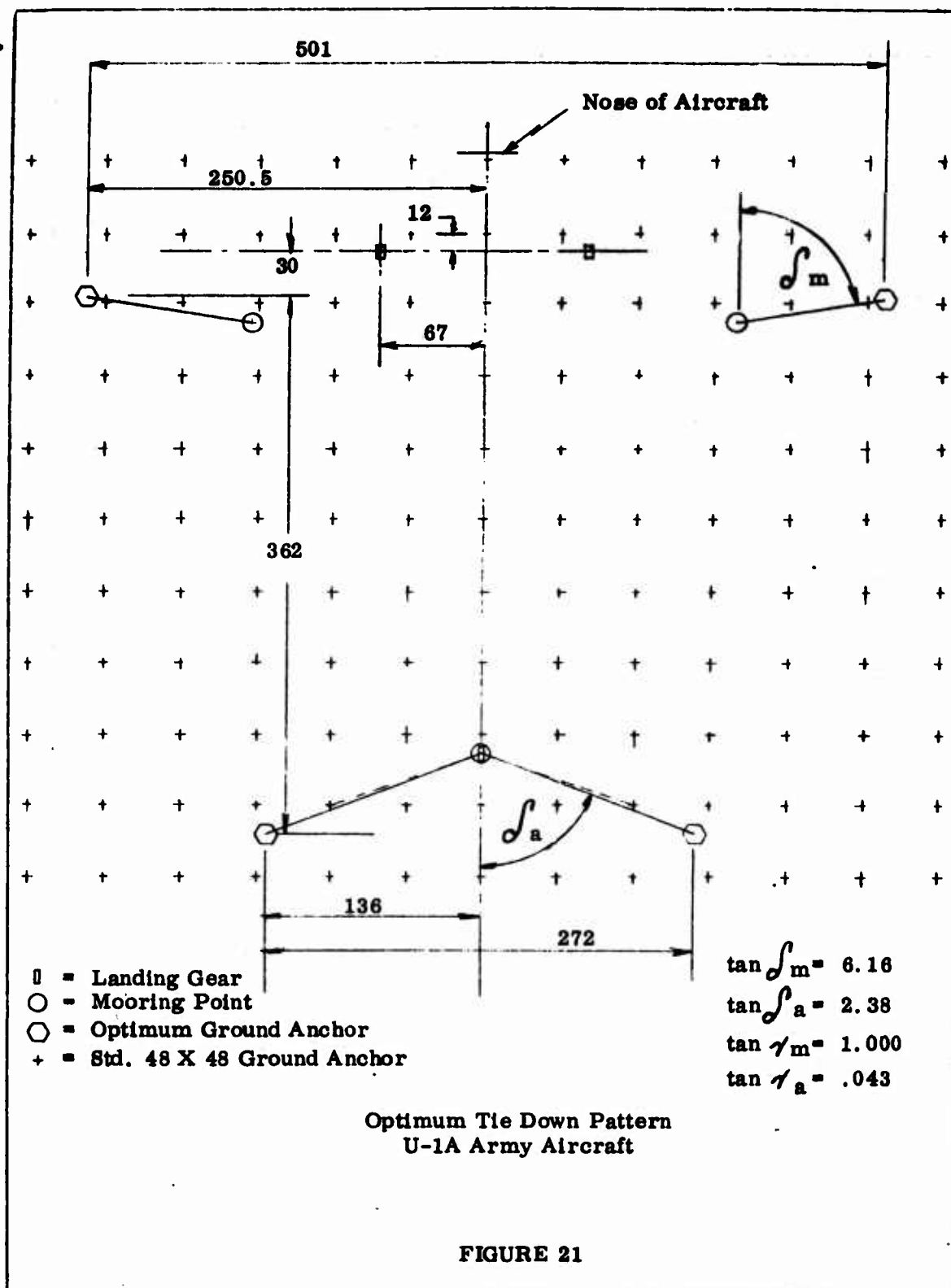
Figures 20 through 28 illustrate the optimum tie-down pattern for each of the nine analyzed aircraft. In each of these figures, a 4' x 4' pattern of ground anchors is also shown to illustrate the proximity that can be attained to the optimum pattern.

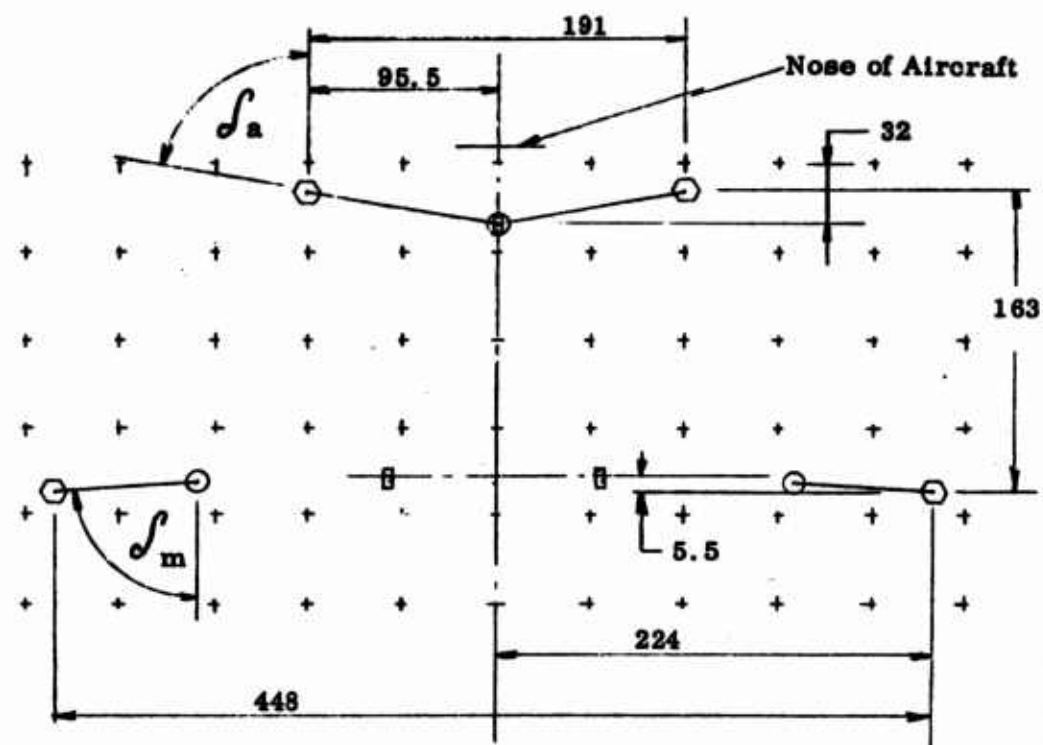
The angles \angle_m and \angle_a shown in these Figures are those calculated and shown previously in Table II and in the design example. The angle \angle_m was arbitrarily selected as 45° while the angle \angle_a was selected to utilize the same length of cable (in the optimum tie-down pattern) as is required at the main mooring point.



Optimum Tie Down Pattern
L-20 Army Aircraft

FIGURE 20



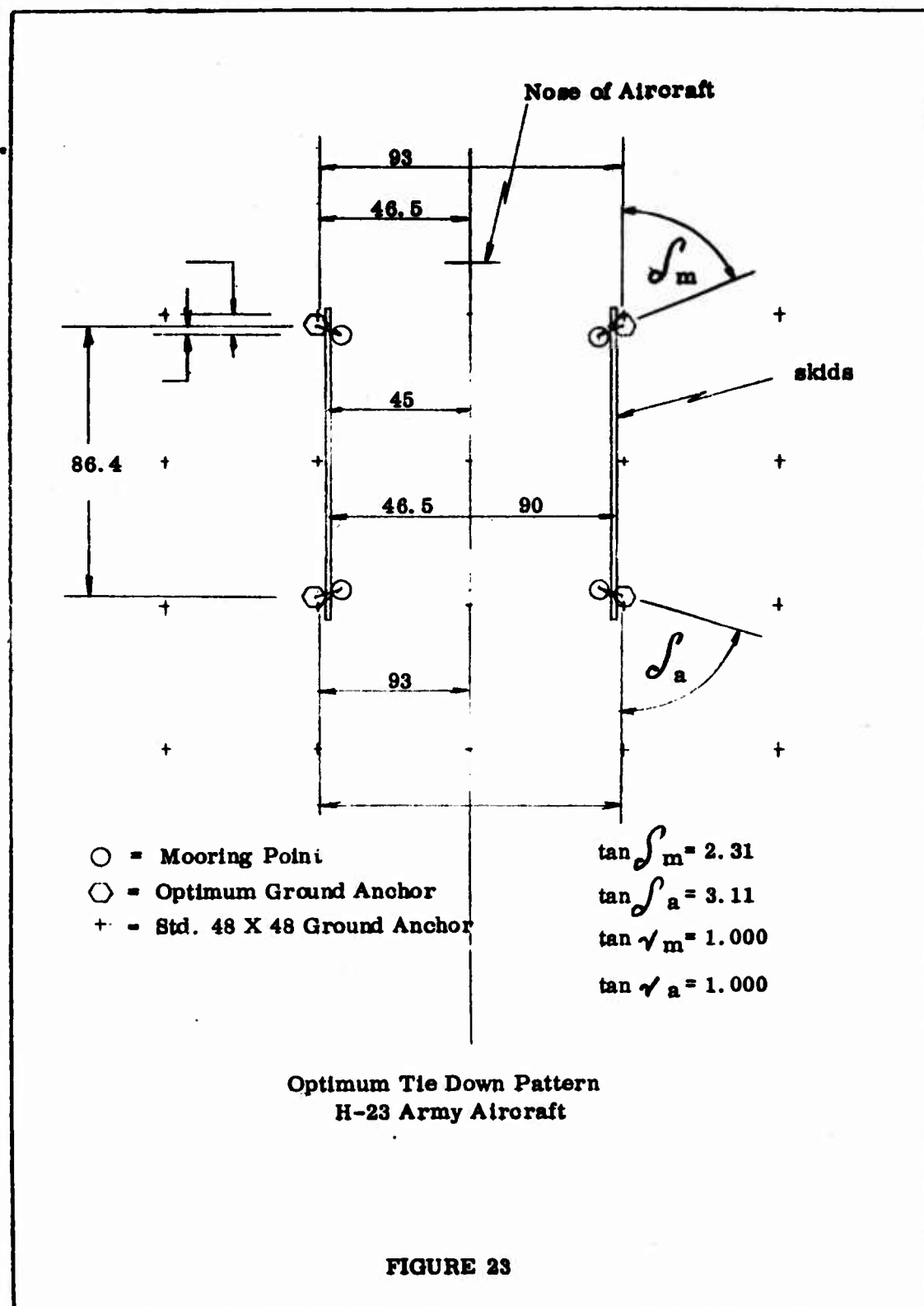


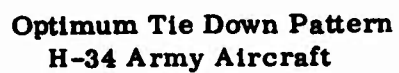
- = Landing Gear
 ○ = Mooring Point
 ⊙ = Optimum Ground Anchor
 + = Std. 48 X 48 Ground Anchor

$$\begin{aligned} \tan \angle_m &= 13.72 \\ \tan \angle_a &= 5.52 \\ \tan \gamma_m &= 1.000 \\ \tan \gamma_a &= .337 \end{aligned}$$

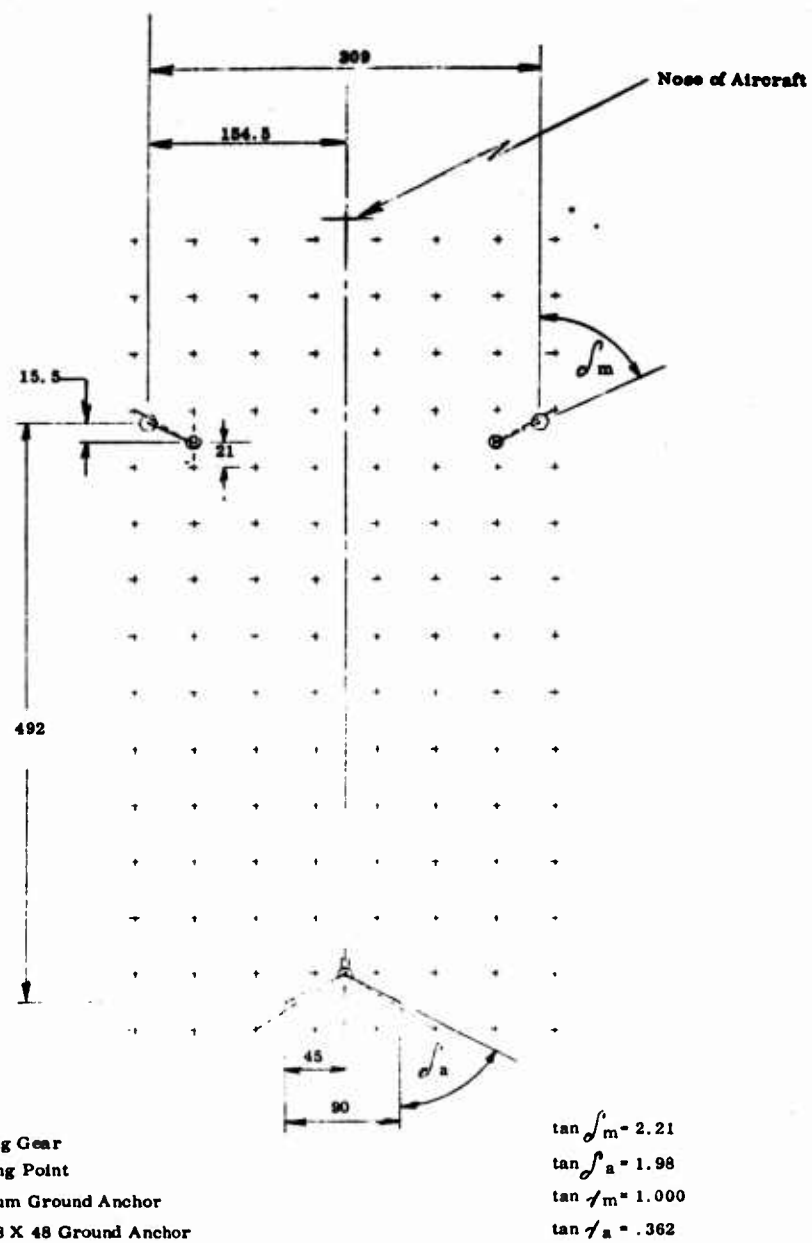
Optimum Tie Down Pattern
AO1-A Army Aircraft

FIGURE 22



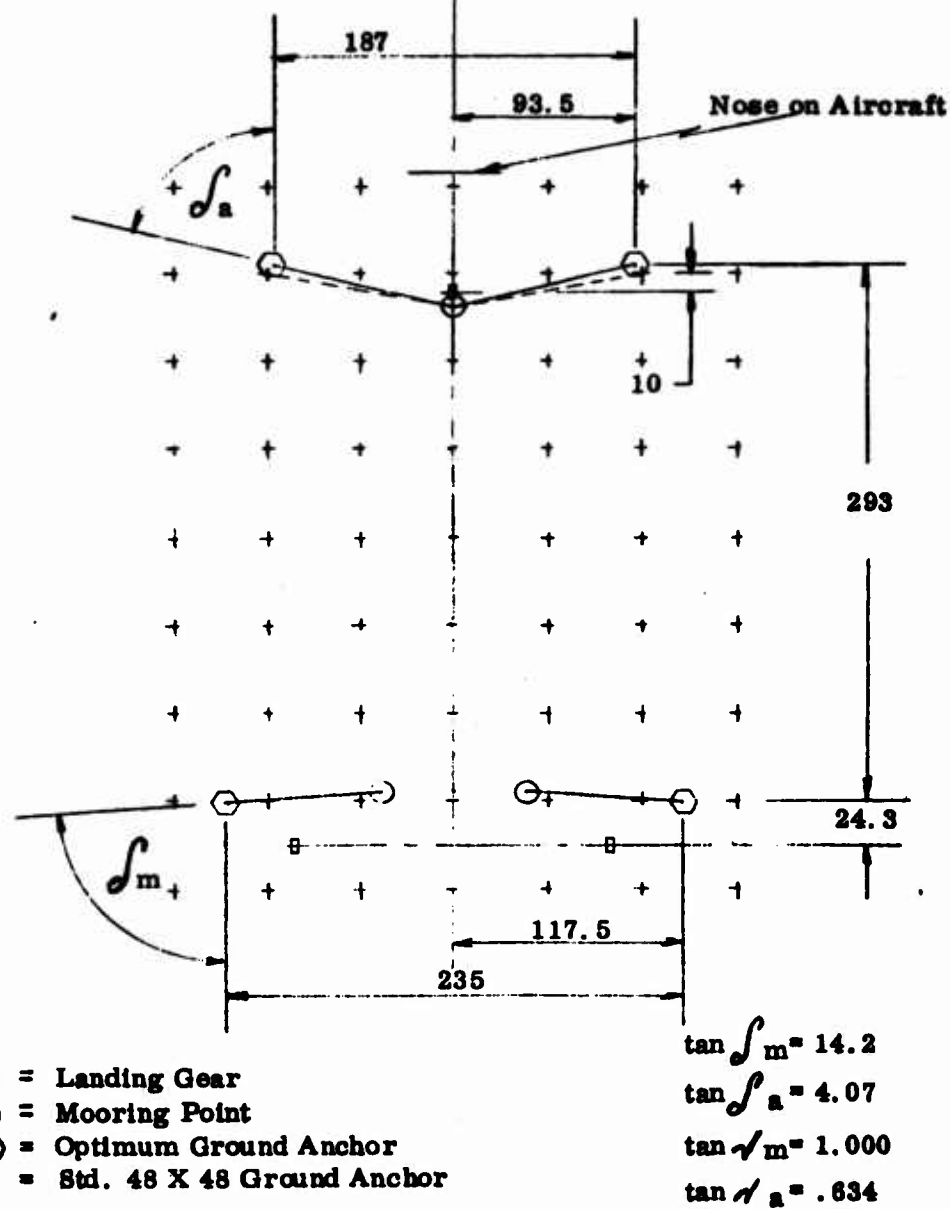


71



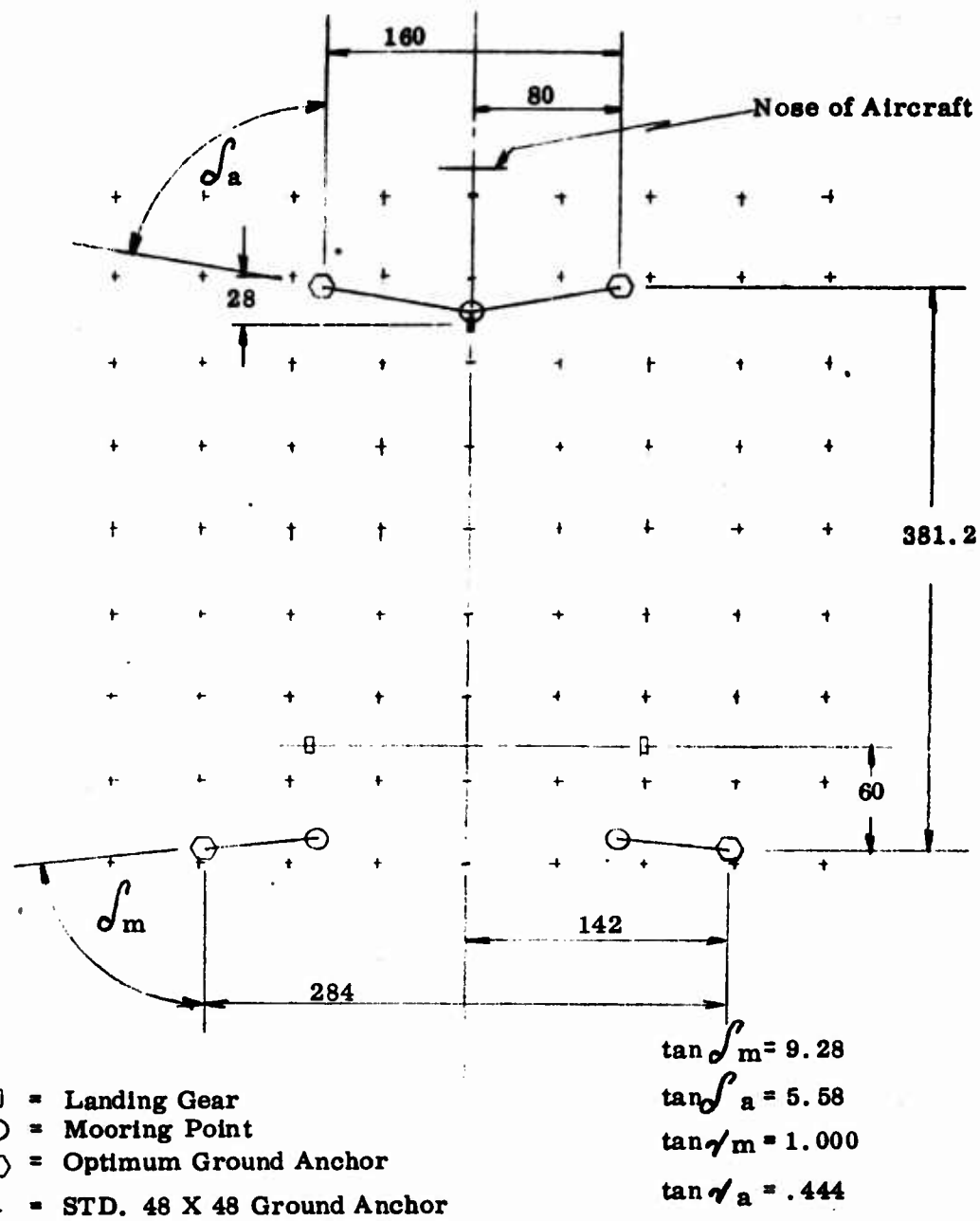
Optimum Tie Down Pattern
H-37 Army Aircraft

Figure 25



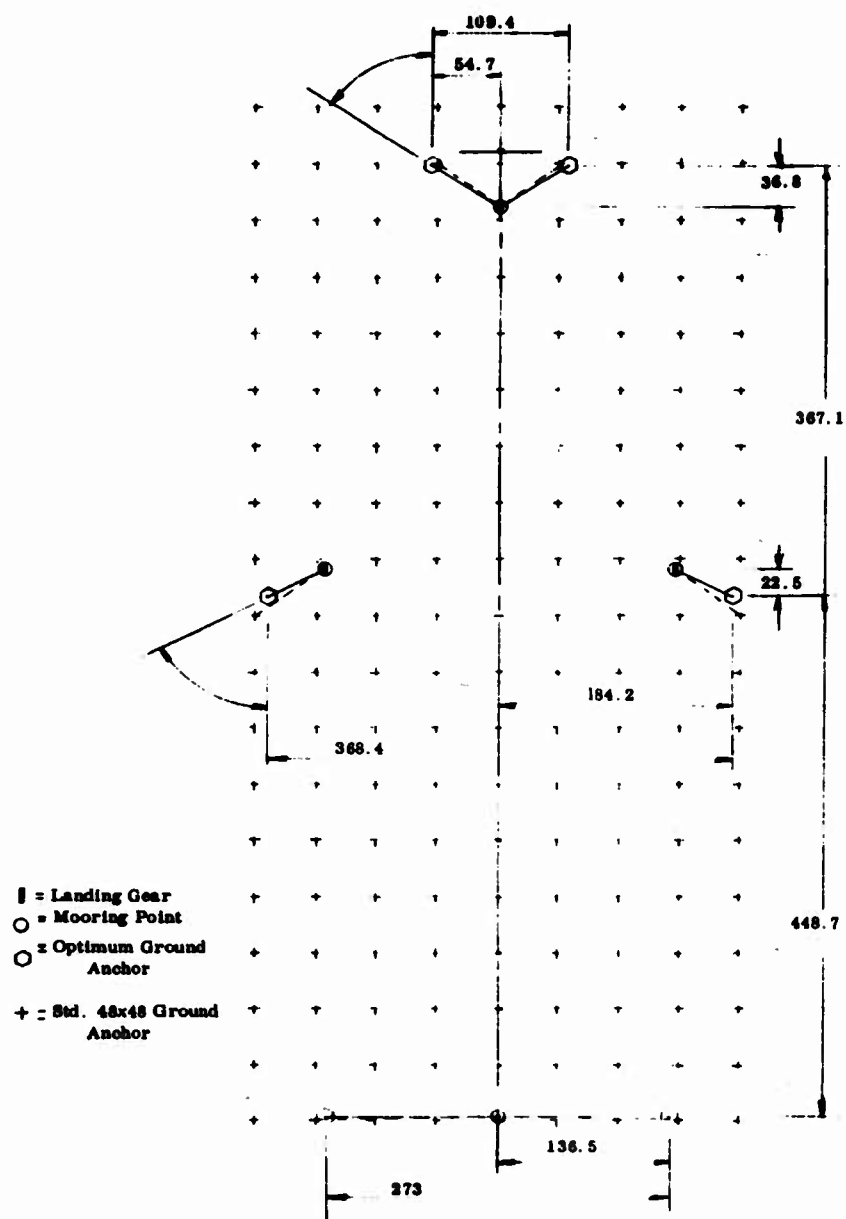
Optimum Tie Down Pattern
H-21 Army Aircraft

FIGURE 26



Optimum Tie Down Pattern
YHC-1 Army Aircraft

FIGURE 27



Optimum Tie Down Pattern
YAC-1 Army Aircraft

Figure 28

SUPPLEMENTAL ENGINEERING REPORT
AIRCRAFT MOORING SYSTEM
(20 May 1960)

I. SCOPE

The scope of this document is to provide information which was not available at the time of the issuance of the original report. This supplement provides data on four Army Aircraft; Bell Aircraft's H-13 and HU-1A, Sikorsky Aircraft's H-19 and Cessna Aircraft's L-19.

A fifth Army Aircraft (Beech Aircraft's L-23) is not included because aerodynamic information cannot be obtained from the manufacturer. (See Appendix)

II. DETAILED ANALYSIS OF AIRCRAFT

In accordance with Sections VII and VIII of the original report the following tabular data is provided. All of the aerodynamic data shown in these supplemental tables was provided by the corresponding manufacturer. Thus there are fewer approximations or projections of data here than in the original report.

Also Cessna provided detailed information on lift coefficients and location of center of lift on the semispan due to a side wind. For this reason Table I was expanded to include v , t , C_l and S' . This data was discussed and considered negligible on pages 31 and 32 of the original report. Inclusion of this data to calculate vertical tension T_3 and optimum angle α_3 for the L-19 craft still provides negative cable tensions, which means wind velocities up to 75 knots should not roll any of these aircraft over.

III. SPECIFIC ANALYSIS

The following Supplemental Tables I, II and III provide additional and corrective information on four Army Aircraft included in the corresponding tables of the original report.

IV. SUMMARY OF DETAILED ANALYSIS

Cessna's L-19 is the only Army Aircraft capable of flying at air speeds at or below 75 knots. This is indicated by the need of a vertical restraining force (T_1') at the main mooring points during a head wind. Calculation of the angle, γ_m , at 61° will provide the required 3420# vertical force component when the cable tension, P_m , of 3910# is attained.

Thus, defining the cable tensions P_m and P_a and the corresponding optimum angles γ_m and γ_a and δ_a and δ_m as indicated in the "Analysis of Maximum Forces at Mooring Points" (Section V of original report) will provide adequate mooring for an aircraft.

SUPPLEMENTAL TABLE I

DATA REQUIRED FOR ANALYSIS OF HORIZONTAL FORCES

DESIG	TYPE	MADE BY	a (in)	b (in)	c (in)	e (in)	g (in)	h (in)	j (in)	l (in)	m (in)	q (psf)	n (in)
H-13	Helicopter with Skids	Bell Helicopter	0	30	30	20	0	52	-30	40	20	.219	27
HU1-A	Helicopter with Skids	Bell Helicopter	0	27.2	43.2	48.8	0	47.9	-43.2	43.2	27.2	.219	30
L-19	Conventional Landing Gear - Highwing	Cessna Aircraft	-10*	207.5*	27.5*	50*	-4*	-25*	1.25	75*	127-1/2*	.219	100
H-19	Helicopter with 4-Wheels	Sikorsky	0	55.7	68.9	19.3	21.6	45.8	-44.7	100	22	.219	34

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DESIG	TYPE	MADE BY	p (in)	s (in)	v (in)	t (in)	W (lbs)	Cl	Cd	S in ²	Cs	Cl'	A in ²	S' in ²
H-13	Helicopter with Skids	Bell Helicopter	45	-2	---	--	2450	---	$C_{ds} = 2300 \text{ in}^2$	$C_{gs} = 2300 \text{ in}^2$	$C_{gs} A = 4600 \text{ in}^2$			---
HU1-A	Helicopter with Skids	Bell Helicopter	50.2	6	---	--	5725	---	$C_{ds} = 2300 \text{ in}^2$	$C_{gs} = 2300 \text{ in}^2$	$C_{gs} A = 4600 \text{ in}^2$			---
L-19	Conventional Landing Gear - Highwing	Cessna Aircraft	45	14	112	20	2400	1.11	.076	25200	.50	.03	25200	25200
H-19	Helicopter with 4-Wheels	Sikorsky	28	2	---	--	7900	---	.5	7800	.5	---	34000	---

* Figures scaled from manufacturer's prints.

SUPPLEMENTAL TABLE II

HORIZONTAL & VERTICAL MOORING POINT FORCES AND OPTIMUM ANGLES

AIRCRAFT	F ₁ '	F ₂	F ₃	F ₄	T ₁ '	T ₂	T ₃	T ₄	tan ∫ _a	tan β ₁	tan α ₃	tan ∫ _m	tan γ _a	tan γ _m
H-13	252#	504#	230#	384#	0	0	0	0	1.53	0	0	.913	0	0
HU1-A	252#	504#	530#	757#	0	0	0	0	3.01	0	0	2.10	0	0
L-19	209	418	1880	1160	3420#	0	0 ^①	0	5.54	16.4	0	8.99	0	1.81 ^②
H-19	428#	855#	932#	3200#	0	0	0	0	7.48	0	0	2.23	0	0

①

T₃ was calculated from equations 14, 20 & 21 including factors v, t, C_l' & S' since the manufacturer provided data for these values.

②

Where T₁' is real and T₃ is zero or negative.

$$\tan \gamma_m = \frac{T_1'}{\sqrt{(F_1')^2 + (F_3)^2}}$$

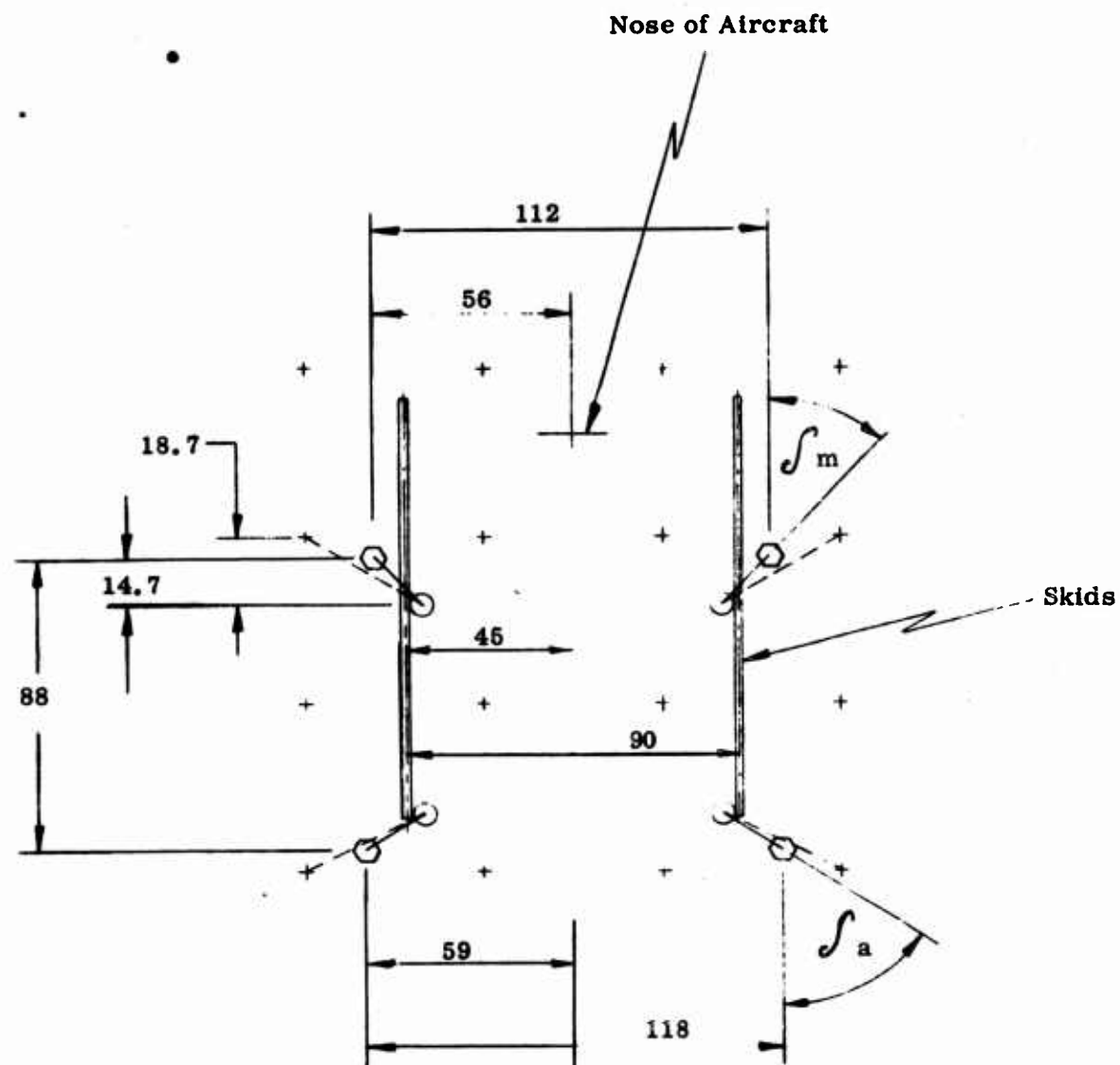
SUPPLEMENTAL TABLE III

TIE DOWN CABLE LOADS AND ANGLES

DESIG	Tan \int_a	Tan \int_m	Tan γ_a		Tan γ_m		P _a	P _m
			Calc.	Assumed	Calc.	Assumed		
H-13	1.53	.913	0	1.000	0	1.000	647	485
HU-1A	3.01	2.10	0	1.000	0	1.000	1150	835
L-19	5.54	8.99	0	.109	1.81	1.81	2090	3910
H-19	7.48	2.23	0	1.000	0	.445	4660	1068

V. OPTIMUM PATTERNS

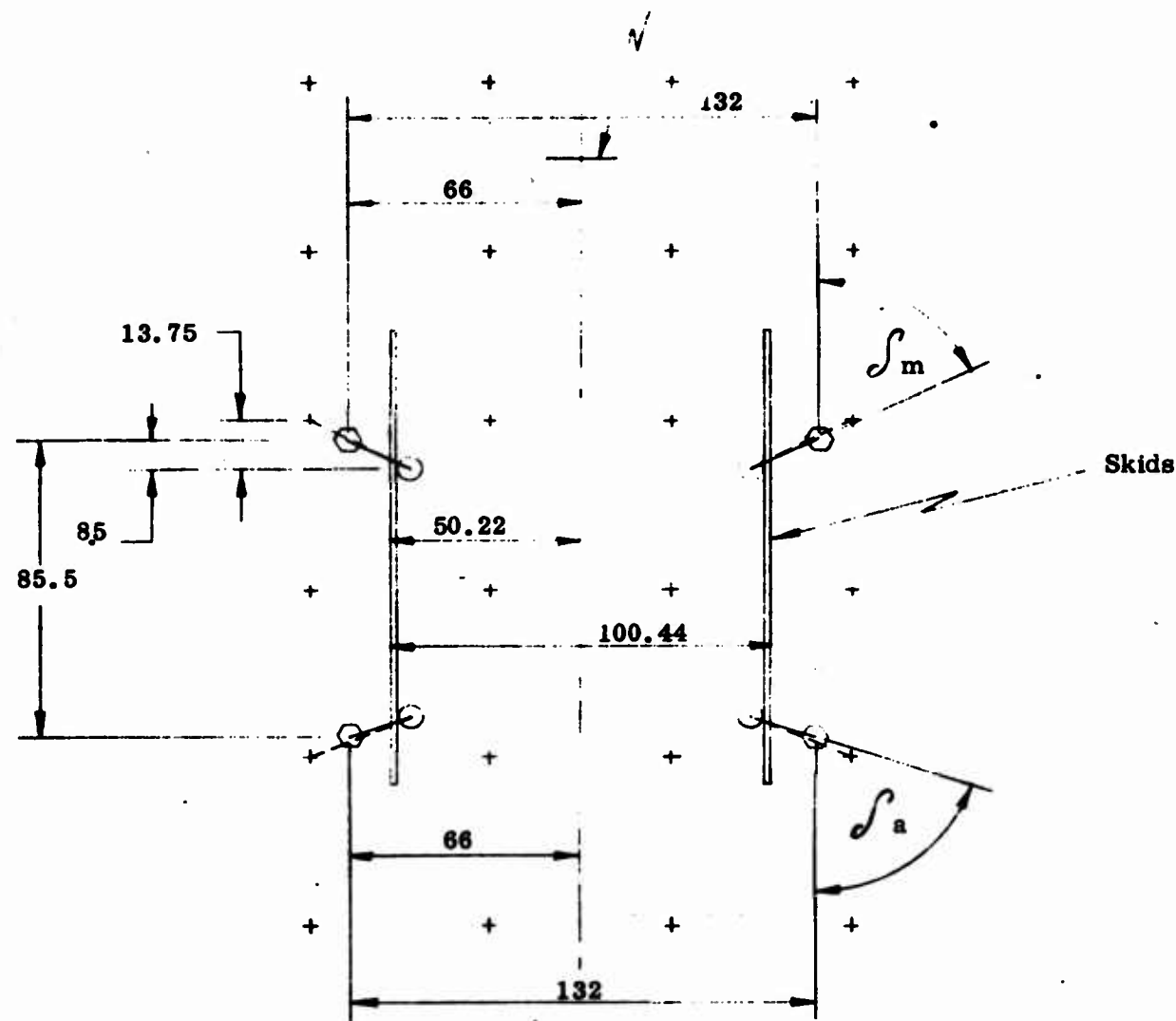
The following figures 26 through 29 inclusive illustrate the calculated optimum pattern superimposed upon the suggested standard, single optimum pattern of Ground Anchors — 48 X 48 inches.



$$\begin{aligned}\tan \angle_m &= .913 \\ \tan \angle_a &= 1.53 \\ \tan \gamma_m &= 1.000 \\ \tan \gamma_a &= 1.000\end{aligned}$$

OPTIMUM TIE DOWN PATTERN
 H-13 ARMY AIRCRAFT
 FIGURE 26

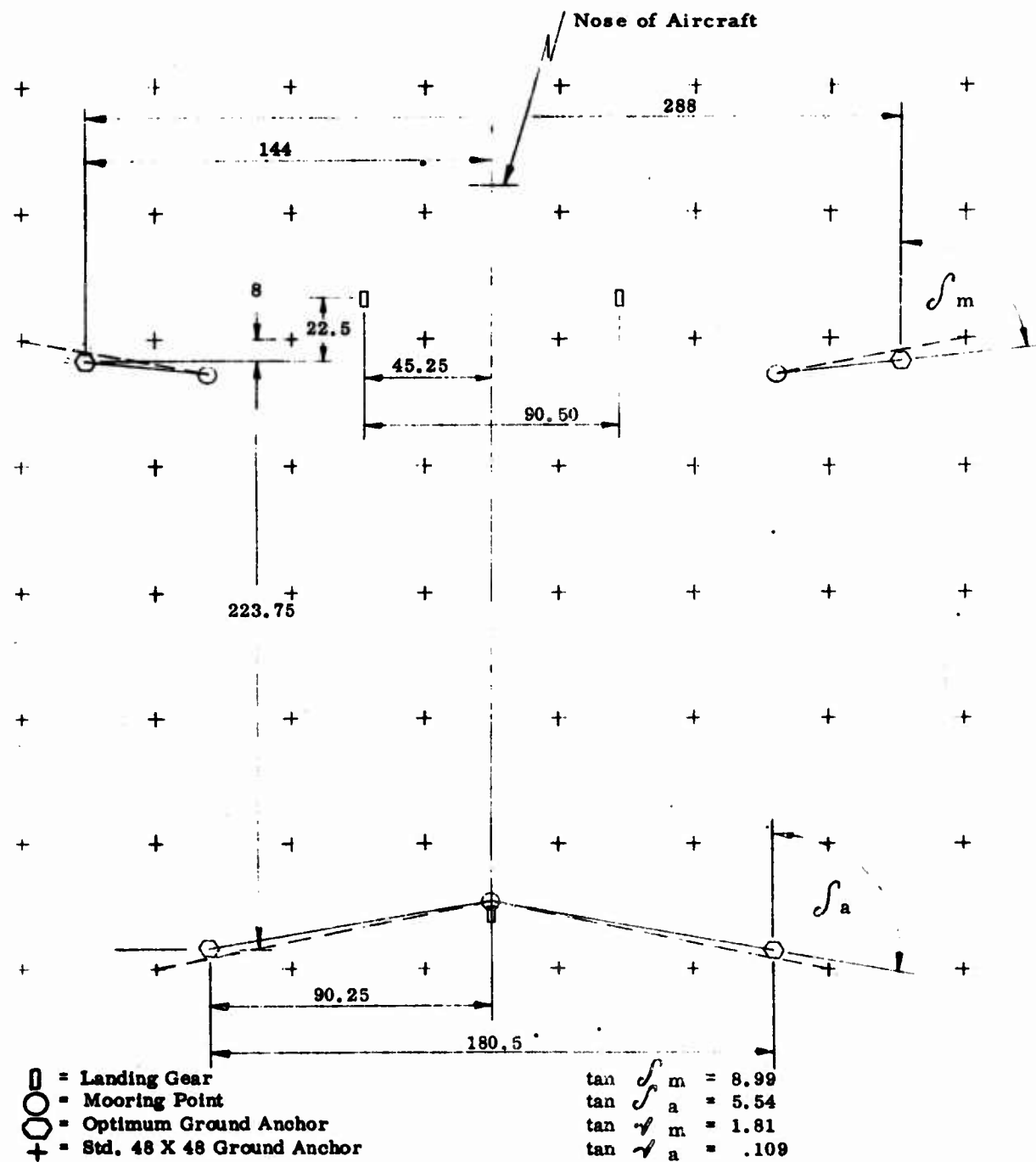
Nose of Aircraft



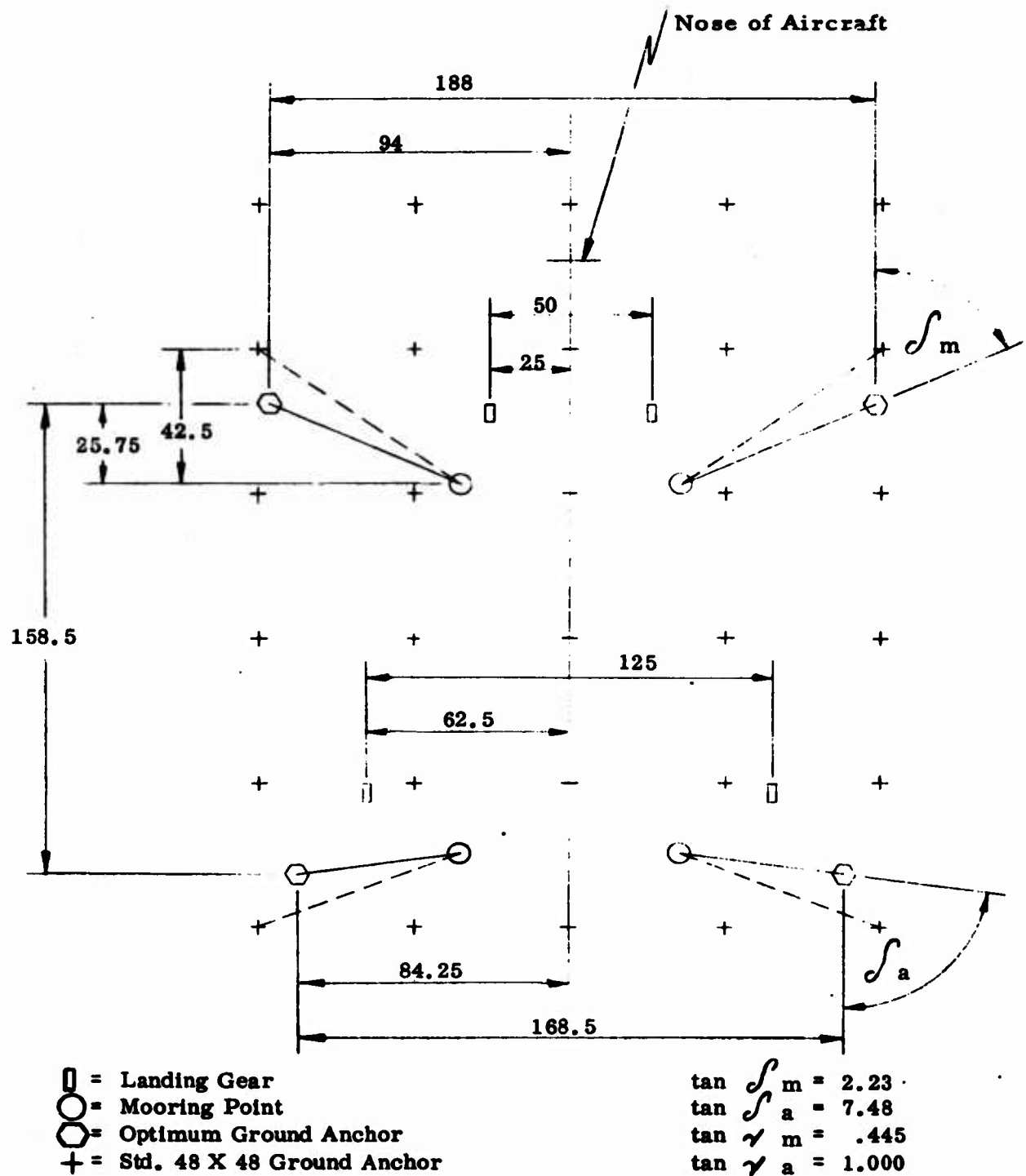
- - Mooring Point
- ⊕ - Optimum Ground Anchor
- + - Std. 48 X 48 Ground Anchor

$$\begin{aligned}\tan S_m &= 2.10 \\ \tan S_a &= 3.01 \\ \tan \gamma_m &= 1.000 \\ \tan \gamma_a &= 1.000\end{aligned}$$

OPTIMUM TIE DOWN PATTERN
HU-1A ARMY AIRCRAFT
FIGURE 27



OPTIMUM TIE DOWN PATTERN
L-19 ARMY AIRCRAFT
FIGURE 28



OPTIMUM TIE DOWN PATTERN
H-19 ARMY AIRCRAFT
FIGURE 29

APPENDIX

A. DATA COLLECTION FOR SUPPLEMENTAL REPORT

Sketches were made of a conventional high-wing aircraft and all required dimensional data was illustrated and defined. Aerodynamic data was also defined. Copies of these sketches were submitted to Cessna, Bell Helicopter, Sikorsky Aircraft and Beech, requesting that they provide all indicated information on their particular crafts. Cessna provided information on their Conventional High-Wing Aircraft, Bell and Sikorsky provided information on their helicopters. A copy of the reply from Beech Aircraft is attached.

If we provide new sketches illustrating a tricycle landing gear craft, they will provide dimensional data but no aerodynamic data. The lack of aerodynamic data will render the dimensional data useless, therefore, we have made no further attempts to obtain any data from Beech Aircraft.

Also attached are copies of our sketches which were sent to the aircraft manufacturers requesting data on their crafts.

BEECH AIRCRAFT CORPORATION
WICHITA 1, KANSAS
U.S.A.

C
O
P
Y

Founded in 1932 by Walter H. Beech

May 25, 1960

In reply please refer
to 905-308

Mr. Edmund F. Moran, Project Engineer
Entwistle Manufacturing Corporation
1475 Elmwood Avenue
Providence 7, Rhode Island

Reference: Your letter of April 19, 1960 requesting information
on Beech L-23 aircraft

Dear Mr. Moran:

Your referenced letter and its attachments have been reviewed
by affected Engineering groups and returned with these comments.

"---The aerodynamic information requested by this letter
is not available and no convenient method is known where-
by the requested information can be obtained. Likewise,
the project group has voiced considerable doubt about the
required physical dimensions as requested in the subject
letter.

For the above reasons it is recommended that Entwistle be
notified that the aerodynamic data which they have re-
quested cannot be furnished and, if the physical dimensions
are necessary to their project, they identify the dimensions
in terms of a tricycle geared airplane.---"

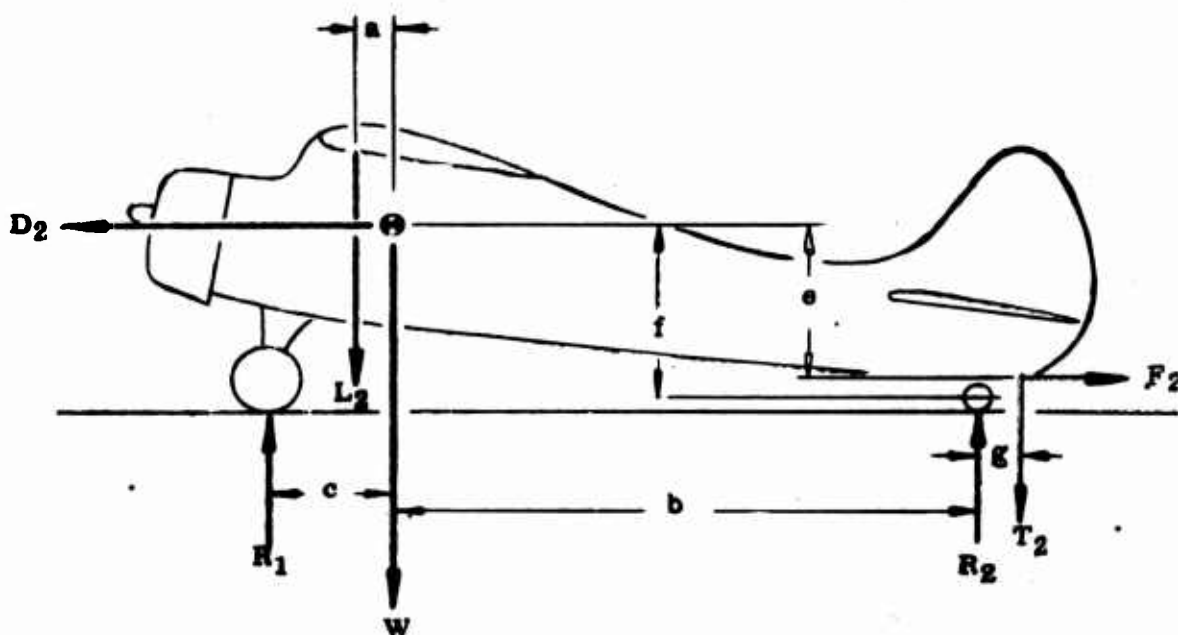
As a result of our review we therefore cannot supply you the
desired information and are returning the attachments herewith.

Yours very truly,

BEECH AIRCRAFT CORPORATION

/s/ W. C. Newman
W. C. Newman
Chief Draftsman

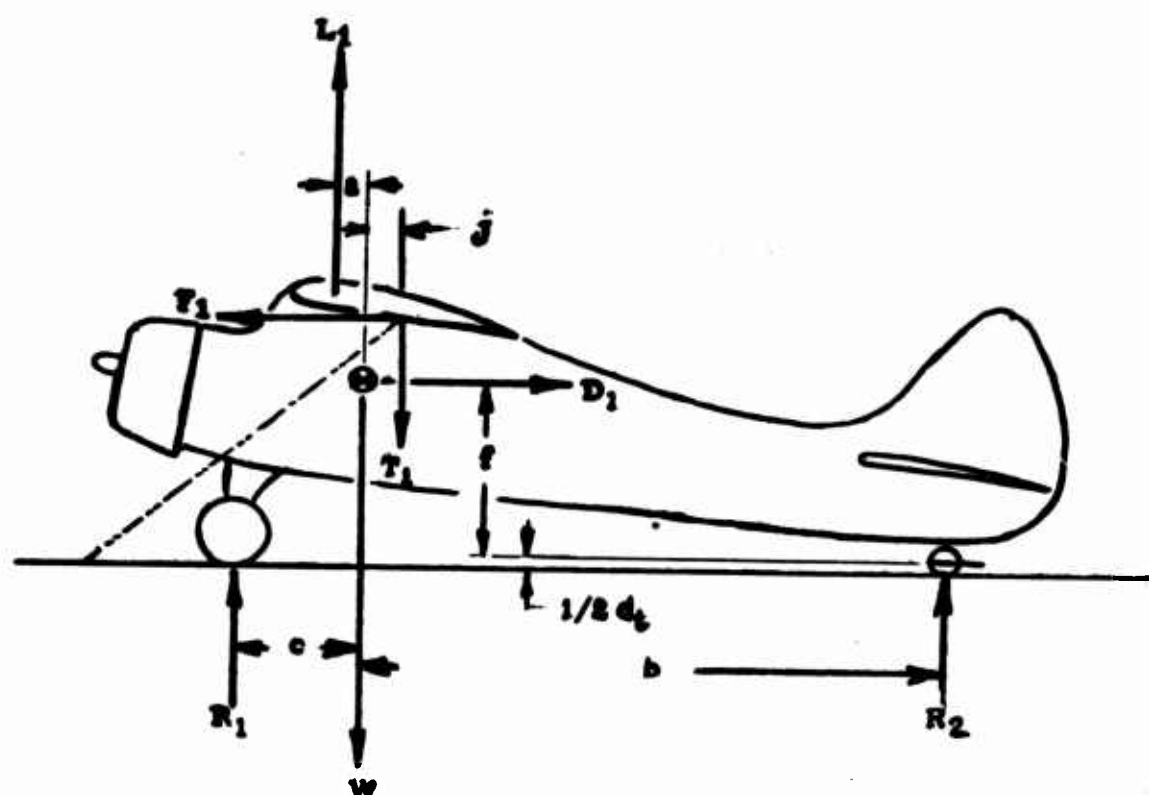
WCN:ked
Enclosures (4)



$a =$ _____ inches (Distance Down From C.G. to Rear Mooring Point)

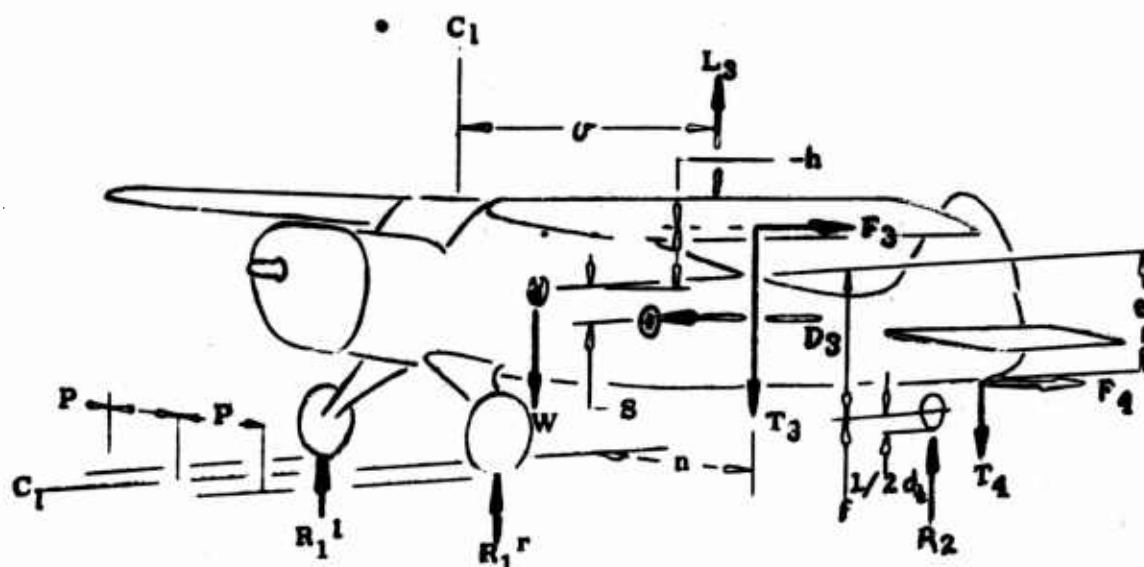
$g =$ _____ inches (Distance Aft From Center of Rear Landing Gear to Rear Mooring Point)

PLEASE DENOTE ANY DIMENSIONS WHICH ARE IN A
DIRECTION OPPOSITE THAT SHOWN BY
NEGATIVE NUMBERS



$a =$ _____ inches (DISTANCE FORWARD FROM C.G. TO CENTER OF LIFT)
 $b =$ _____ inches (DISTANCE AFT FROM C.G. TO REAR LANDING GEAR)
 $c =$ _____ inches (DISTANCE FORWARD FROM C.G. TO FWD LANDING GEAR)
 $j =$ _____ inches (DISTANCE AFT FROM C.G. TO FWD MOUNTING POINT)
 $f =$ _____ inches (HEIGHT FROM CENTER OF REAR LANDING GEAR TO C.G.)
 $W =$ _____ lbs GROSS WEIGHT OF CRAFT

PLEASE DENOTE ANY DIMENSIONS WHICH ARE IN
 A DIRECTION OPPOSITE THAT SHOWN
 BY NEGATIVE NUMBERS



h inches (DIMENSION DOWN FROM C.G. TO HORIZONTAL PLANE OF THE FORWARD MOORING POINT)

n inches (LATERAL DIMENSION FROM PLANE OF SYMMETRY TO FWD MOORING POINT)

p inches (LATERAL DIMENSION FROM PLANE OF SYMMETRY TO CENTER OF FWD LANDING GEAR)

s inches (VERTICAL DISTANCE DOWN FROM C.G. TO CENTER OF PRESSURE IN A SIDE WIND)

C_L (LIFT COEFFICIENT - HEADWIND - MOORED ATTITUDE)

C_D (DRAG COEFFICIENT - HEADWIND - MOORED ATTITUDE)

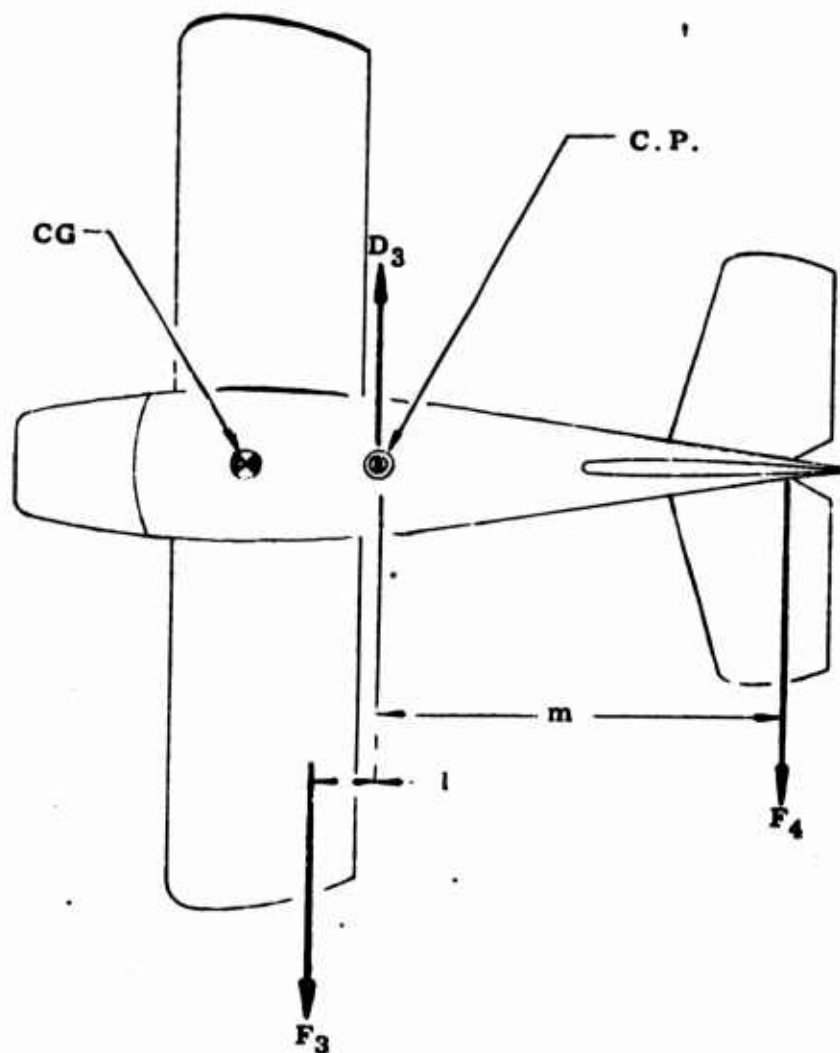
S sq. ft. (CHARACTERISTIC AREA FOR USE WITH C_L & C_D)

C_{SD} (DRAG COEFFICIENT - SIDE WIND - MOORED ATTITUDE)

C_{SL} (LIFT COEFFICIENT - SIDE WIND - MOORED ATTITUDE)

S_S sq. ft. (CHARACTERISTIC AREA FOR USE WITH C_{SD} & C_{SL})

u inches (DISTANCE FROM PLANE OF SYMMETRY TO CENTER OF LIFT ON SEMISPAN IN SIDE WIND)



$l =$ _____ inches (DISTANCE FORWARD FROM CENTER OF PRESSURE
DUE TO SIDE WIND TO FORWARD MOORING POINT)

$m =$ _____ inches (DISTANCE AFT FROM C. P. TO REAR MOORING
POINT)

EVALUATION

The test program established that the Universal Ground Anchor had the greatest ground-holding capability of all the anchors tested, but none of the anchors met the ground-holding capabilities specified in the military and technical characteristics. The Universal Ground Anchor was also found to be the easiest to install. It is the lightest in weight excluding the driving rod. The test engineer recommended that an estimate be made of the weight that could be saved by modification, such as by the use of stainless steel wire, aluminum thimbles, and a heat-treated, alloy steel driving rod.

The inadequacy of the equipment tested indicated that a new approach to the mooring system problem was required. The staff study performed to re-evaluate the mooring system problem disclosed the following factors that had not been previously investigated:

1. An engineering relationship in terms of force distribution exists between aircraft mooring points and the ground's capability to withstand resultant aerodynamic forces.
2. The holding capabilities of mooring anchors vary in accordance with the characteristics of the soil in which the anchors are emplaced.
3. Theoretical forces affecting mooring systems can be determined by computing the aerodynamic forces that result from assumed surface wind velocities that react on the airfoils and/or the flat-plate areas of each specific Army aircraft.
4. Current mooring points on Army aircraft and specified aircraft mooring patterns do not utilize available mechanical advantages to reduce tie-down loads.

These factors indicated that the aircraft mooring problem was complex and could not be solved simply by improvement of the mooring devices. The resultant contractual studies corroborated the theories advanced in the staff study. An analysis was made of the forces induced on each Army aircraft by the dynamic action of wind velocities on the airfoils and/or flat-plate areas. Data and calculations covering these areas are contained in the contractor's Engineering Report (Part 3, Test Procedures and Results). After the force vectors had been established, the optimum tie-down geometry for restraining these forces was determined. A procedure for

determining optimum mooring point locations on future aircraft was also established. The ideal time to establish these locations is during the development cycle of the aircraft. At this time, the force vectors can be obtained during accumulation of wind-tunnel data. After the forces to be absorbed have been established, the optimum distribution of the forces to the ground may be accomplished by proper placement of the mooring points. The fewer anchors that are required for a given aircraft, the more efficient the mooring system will be.

Termination of this program has precluded the establishment of the feasibility of the proposed system; however, sufficient data are available to complete the system and to perform the required test program. Additional investigations will be necessary regarding the emplacement of mooring anchors under arctic conditions. As indicated in the test report received from the U. S. Army Arctic Test Board, neither the Universal Ground Anchor nor the Standard Arrow were suitable for use in an aircraft mooring system under arctic winter conditions.

APPENDIX I

R & D Task CARD		TYPE OF REPORT Progress		REPORT CONTROL SYMBOL CECRO-1 (RT)	
1. TASK TITLE Aircraft Mooring Equipment (U)		2. SECURITY OF Task U		3. PROJECT NO. 9M89-02-015	
		4. Task Nr. 9M89-02-015-08		5. REPORT DATE 31 Dec 59	
6. BASIC FIELD OR SUBJECT Maintenance, Operating and Servicing Equipment		7. SUB FIELD OR SUBJECT SUB GROUP Aircraft		7A. TECH. OBJ. 80-14	
8. COGNIZANT AGENCY Transportation Corps.		12. CONTRACTOR AND/OR LABORATORY Entwistle Mfg. Corp.		CONTRACT/W. O. NO. DA 44-177-TC-590	
9. DIRECTING AGENCY U.S. Army TRECOM					
10. REQUESTING AGENCY Transportation Corps					
11. PARTICIPATION AND/OR COORDINATION Dept of Air Force (I) Dept of Navy (I) USCONARC (C) Corps of Engineers (C)		13. RELATED PROJECTS None		17. EST. COMPLETION DATES	
				RES. Jan 61	
				DEV.	
				TEST	
				OP. EVAL. Jun 62	
		14. DATE APPROVED 19 Jul 56		18. FY. FISCAL ESTIMATES	
		15. PRIORITY 3		PR 21M	
		16. Budget code: 1.50		60 0	
				61 25M	
19. REPLACED PROJECT CARD AND PROJECT STATUS Replaces task Card dtd 31 Dec 57, Task 114AV, Project 9-89-02-000				T 46M	
20. REQUIREMENT AND/OR JUSTIFICATION A requirement exists for aircraft flyaway ground mooring equipment to protect Army aircraft from being damaged from high winds when parked on soil or frozen surfaces, particularly where permanent facilities are not available. No CDOG reference.					
21. BRIEF OF AND OBJECTIVE a. Brief of Task/Project and objective: (1) Due to mobility requirements of the Army, and current dispersion criteria equipment is necessary to moor aircraft where permanent facilities are not available. In order to make this possible, equipment capable of being transported by the individual aircraft without impairing the performance of its normal functions must be developed. (2) The immediate objective is to design and develop aircraft flyaway mooring equipment capable of meeting the requirement. The ultimate objective is to classify the items as Standard Army equipment.					
22. OASD (R & D)		SN.	CN.	C.	X. I. C.
DD FORM 613 1 APR 55 REPLACES DD FORM 613, 1 JAN 52.				PAGE 1 OF 3 PAGES	

R&D Task CARD
CONTINUATION SHEET

1. Task TITLE Aircraft Mooring Equipment (U)	2. SECURITY OF Task U 4. Task Nr. 9M89-02-015-08	3. PROJECT NO. 9M89-02-015 5. REPORT DATE 31 Dec 57
---	---	--

b. Approach:

- (1) Conduct necessary preliminary design studies and develop promising designs. Coordinate with Corps of Engineers on the characteristics of soil and snow as developed by studies conducted by SIPRE and WES.
- (2) Procure two prototypes of developed equipment.
- (3) Conduct appropriate engineering and user tests.
- (4) Accomplish necessary modifications and retests.
- (5) Prepare suitable reports as required.
- (6) Accomplish necessary type classification action.
- (7) Specifically review the item for maximum use of standard components during the design, prototype construction and test phases.
- (8) Commercial contracts will be utilized as required.

c. Tasks: None

d. Other information:

- (1) Scientific research: Not contemplated.
- (2) Standardization item: Not applicable.
- (3) Engineering test: Not applicable.
- (4) Operational availability date: June 1962
- (5) Same or related items: None
- (6) Specific review points: Not applicable.
- (7) Other funds: Prior Year O&M, A \$2M

e. Background history and progress:

- (1) Background history: Task initiated in July 1956, for aircraft flyaway ground mooring equipment to protect Army aircraft from being damaged from high winds when parked on soil or frozen surfaces. A new type mooring anchor was

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1 FEB 56
REPLACES DD FORM 613-1,
1 FEB 55

PAGE 2 OF 3 PAGES

R&D Task CARD
CONTINUATION SHEET

1. Task TITLE Aircraft Mooring Equipment (U)	2. SECURITY OF Task U 4. Task Nr. 9M89-02-015-08	3. PROJECT NO. 9M89-02-015 5. REPORT DATE 31 Dec 59
---	---	--

designed and constructed by TRECOM for testing. Evaluation of other improved tie-down materiel is being conducted. The number of the task was changed to 114AV by the TC Technical Committee on 20 December 1956. Test results were not conclusive and task was temporarily suspended due to higher priority work. Task reassigned from 9-89-02-000 to Project 9M89-02-015.

(2) Progress: New study conducted and staff study completed in April 59. Results provided information to conduct further research study and investigation. Contract DA 44-177-TC-590 was initiated in June 59 with Entwistle Mfg. Corp. to conduct further investigation in required aircraft mooring points, tie-down pattern and recommended test bed equipment.

f. Future plans: Continue research and investigation in the area of aircraft design for tiedown, tiedown hardware, soils and surface problems including the performance of extensive tests on proposed concepts. Review and analyze the results of tests and reports, and recommend further action accordingly. This task will be revised, renumbered and retained by USATRECOM for prosecution.

g. References:

(1) TCTC Item 1280, Meeting 90, held 4 November 1954, Research and Development Project 9-89-02-000, Army Aircraft Maintenance, Operating and Servicing Equipment, Investigation, Development, Modification and Test of; initiation of project approved.

(2) TCTC Record and Information Item 1719, Meeting 102, held 22 March 1956, Consolidation of Projects; changing title of Project 9-89-02-000 to Army Aircraft Support.

(3) TCTC Item 1810, Meeting 104, held 19 July 1956, Subtask 114AV, Project 9-89-02-000, Aircraft Mooring Equipment; approval of military characteristics of item and initiation of subtask approved.

(4) TCTC Item 1896, Meeting 107, held 20 December 1956, Development Project 9-89-02-000, Army Aircraft Support; revision of project approved.

(5) TCTC Record and Information Item 1934, Meeting 107, held 20 December 1956, Change in Numbers and Titles of Development Subtasks Assigned Under Development Project 9-89-02-000, Army Aircraft Support, recording change in subtask number from 114AM to 114AV. (Subsequently redesignated as Task 114AV)

(6) TCTC Record and Information Item 3313, Meeting 126, held 17 December 1959, Renumbering of Transportation Corps Research and Development Projects and Tasks; Changes in Titles.

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1 FEB 56
REPLACES DD FORM 613-1,
1 FEB 55.

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APPENDIX II

MILITARY CHARACTERISTICS

1. General

a. The item shall contain the minimum number of components necessary to moor Army aircraft when parked on soil or frozen surfaces where permanent mooring facilities are not available.

b. The item shall be designed as flyaway equipment suitable for transport by all Army aircraft.

c. The item and its components shall be as light in weight and as compact as possible within the strength requirements.

d. The item and its components shall be designed for a minimum life of three years normal usage, with a minimum of inspection and maintenance.

e. The item and its components shall be highly resistant to deterioration, including that caused by moisture, solvents, chemicals, petroleum products, temperature and sunlight.

f. The item shall be capable of withstanding a pull of at least 3,000 pounds at 45 degrees from the vertical and a vertical pull of at least 2,000 pounds.

2. Materials

The item shall be constructed of readily available nonstrategic and non-critical materials to the extent practicable for the service intended. Materials and components shall be suitable for their purpose.

3. Temperature Limitations

The item shall be designed to have the inherent capability of acceptable performance within an air temperature range extending from $+125^{\circ}\text{F}$. (minimum exposure of 4 hours with full impact of solar radiation, 360 BTU/Ft Sq/Hr) to -65°F . (minimum exposure of 3 days without benefit of solar radiation). The item must be susceptible of safe storage and

transportation without permanent impairment of its capabilities from the effects of temperature from $+160^{\circ}\text{F.}$ for periods as long as 4 hours per day to -80°F. for periods of 24 hours duration.

4. Transportability

Unrestricted air and surface transportability is required.

5. Manufacture

The design shall insure maximum practicable interchangeability of components and shall be suitable for production in quantities for which there are potential requirements.

6. Radio Interference Suppression

Not applicable.

7. Packaging and Packing

The item shall be designed for efficient and practicable packaging and packing for export shipment with suitable protection for component parts during handling and transport and for ease of erection at destination.

8. Maintenance

The item shall be designed for ease of maintenance at low cost.

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APPENDIX III

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TECHNICAL CHARACTERISTICS

1. The kit shall be suitable for use with all Army aircraft.
2. The kit shall be capable of one-man operation.
3. The kit shall require no special equipment for installation or removal.
4. Kit shall contain the maximum number of recoverable or reusable components as practicable.
5. The kit shall be inclosed in a package suitable for stowage within the aircraft.

DISTRIBUTION

UNITED STATES CONTINENTAL ARMY COMMAND

Commanding General
United States Continental Army Command
ATTN: Materiel Developments
Fort Monroe, Virginia (2)

Officer in Charge
U. S. Army Transportation Aviation Field Office
ATTN: ALO - Room 1716
Bureau of Naval Weapons, Department of the Navy
Washington 25, D. C. (1)

TRANSPORTATION CORPS

Chief of Transportation
ATTN: TCDRD (2)
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ATTN: TCREG (1)
ATTN: TCSOP (1)
ATTN: TCCAD (1)
Department of the Army
Washington 25, D. C.

Commanding General
U. S. Army Transportation Materiel Command
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U. S. Army Transportation Board
Fort Eustis, Virginia (1)

Commanding Officer
USA Transportation Research Command Liaison Office
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Transportation Corps Liaison Officer
U. S. Army Engineer Research and Development Laboratories
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Fort Belvoir, Virginia (1)

U. S. Army Transportation Corps Liaison Officer
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<p>AD- Army Transportation Research Command, Fort Eustis, Virginia AIRCRAFT MOORING EQUIPMENT, by Robert M. Bernardin. Final rept. on Task 9M89-02-015-08. Jun 61. 101 p. incl. illus. tables. (TREC technical rept. 61-12) Unclassified report</p> <p>This report covers the testing and evaluation of devices and methods for mooring Army aircraft. Included are data pertaining to the ground-</p>	<p>UNCLASSIFIED AD- 1. Mooring - Aircraft 2. Anchors - Aircraft 3. Aircraft Equipment Unclassified report</p> <p>This report covers the testing and evaluation of devices and methods for mooring Army aircraft. Included are data pertaining to the ground-</p>	<p>UNCLASSIFIED 1. Mooring - Aircraft 2. Anchors - Aircraft 3. Aircraft Equipment</p>
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